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

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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 using an integrated luminosity of 373 pb^{-1}. The masses, widths and helicity parameters of these resonances were determined and compared with previous ZEUS measurements of an independent sample [1] with an integrated luminosity of 126 pb^{-1} and theoretical expectations [2]. The results were also compared with PDG values [3] and new high precision measurements by BABAR [4]. A good agreement between the ZEUS and BABAR results is observed.

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1. Introduction

The large charm production cross section in ep collisions at HERA allows to study exited charm meson states. In this paper results for $D_1(2420)^0$ and $D_2^*(2460)^0$ mesons measured with the ZEUS detector using an integrated luminosity of 373 pb^{-1} are reported. Orbitally exited states $D_1(2420)^0$ with $J^P = 1^+$ and $D_2^*(2460)^0$ with $J^P = 2^+$ were studied in the decay modes: $D_1^0 \to D^{*\pm}\pi^\mp$ and $D_2^{*0} \to D^{*\pm}\pi^\mp, D^\pm\pi^\mp$. The width of the D_1^0 $(53.2 \pm 7.2(stat.)^{+3.3}_{-4.9}(syst.)$ MeV) [1] was above the world average value 20.4 ± 1.7 MeV [3]. In addition, a study of the helicity angular distribution of the $D_1(2420)^0$ was consistent with some S-wave admixture in the decay $D_1^0 \to D^{*\pm}\pi^\mp$, contrary to theoretical predictions [2] and to previous experimental results [5, 6] which yielded a pure D-wave decay in this channel.

In this paper we repeated the analysis with an independent data sample of higher integrated luminosity. The new analysis was performed using data taken from 2003 to 2007 with the upgraded ZEUS detector, which included a Micro-Vertex Detector (MVD). The data correspond to an integrated luminosity of $373 pb^{-1}$. To maximise the statistics, events with both photoproduction (PHP) and deep-inelastic scattering were used in this analysis. Events produced in the PHP regime contributed 70-80% of the selected charm meson samples.

2. Results

$D^{*\pm}$ mesons were identified from the decay mode $D^{*\pm} \to D^0(K^\mp\pi^\pm)\pi_s^\pm$ where π_s is low-momentum ("soft") pion using small mass difference between D^* and D^0, $\Delta M = M(D^*) - M(D^0)$. A D^* signal of $66,804 \pm 448$ events with $144 < \Delta M < 147$ MeV was used to reconstruct the excited charm mesons signal. $D^\pm$ mesons were identified from the decay mode $D^\pm \to K^\mp\pi^\pm\pi^\pm$. Measured decay length between the production point and decay vertex of the $D^\pm$ meson was supposed to be greater than 3 times its uncertainty to improve the signal to background ratio. A $D^\pm$ signal of $53,902 \pm 446$ events with $1.85 < M(K\pi\pi) < 1.89$ GeV was used for the excited charm mesons analysis.

The $D_1(2420)^0$ and $D_2^*(2460)^0$ mesons were reconstructed in the decay mode $D^{*\pm}\pi_a^\mp$ where π_a is the additional pion combined with the D^*. For each excited charm meson candidate the "extended" mass difference, $\Delta M^{ext} = M(K\pi\pi_s\pi_a) - M(K\pi\pi_s)$, was calculated. Fig. 1(upper plot) shows the invariant mass, $M(D^{*+}\pi_a) = \Delta M^{ext} + M(D^{*+}_{PDG})$, where $M(D^{*+}_{PDG})$ is the nominal D^{*+} mass [3]. A clear signal of the combined D_1^0/D_2^{*0} mesons is seen. The $D_2^*(2460)^0 \to D^+\pi^-$ decay mode was reconstructed by calculating the "extended" mass difference, $\Delta M^{ext} = M(K\pi\pi\pi_a) - M(K\pi\pi)$. Fig. 1(lower plot) shows the invariant mass, $M(D^+\pi_a^-) = \Delta M^{ext} + M(D^+_{PDG})$, where $M(D^+_{PDG})$ is the nominal D^+ mass [3]. A clear signal of the D_2^{*0} mesons is seen.

The D_1^0 and D_2^{*0} helicity angular distributions were used to distinguish between $D_1^0/D_2^{*0} \to D^{*\pm}\pi^\mp$. The helicity angle α determined as an angle between π_a and π_s momenta in the $D^{*\pm}$ rest frame can be parametrised as $dN/d\cos\alpha \propto 1 + h\cos^2\alpha$, where h is the helicity parameter predicted to be $h = 3$ for D_1^0 and $h = -1$ for D_2^{*0} [2]. Fig. 2 shows the $M(D^{*+}\pi_a)$ distributions in four helicity bins. The D_1^0 contribution increases with $|\cos\alpha|$ and dominates for $|\cos\alpha| > 0.75$. A simultaneous fit was performed on the $M(D^+\pi_a)$ distribution (Fig. 1(lower plot)) and the $M(D^{*\pm}\pi_a)$ distributions in four helicity bins (Fig. 2) to extract the D_1^0 and D_2^{*0} masses, widths and yields. Each resonance

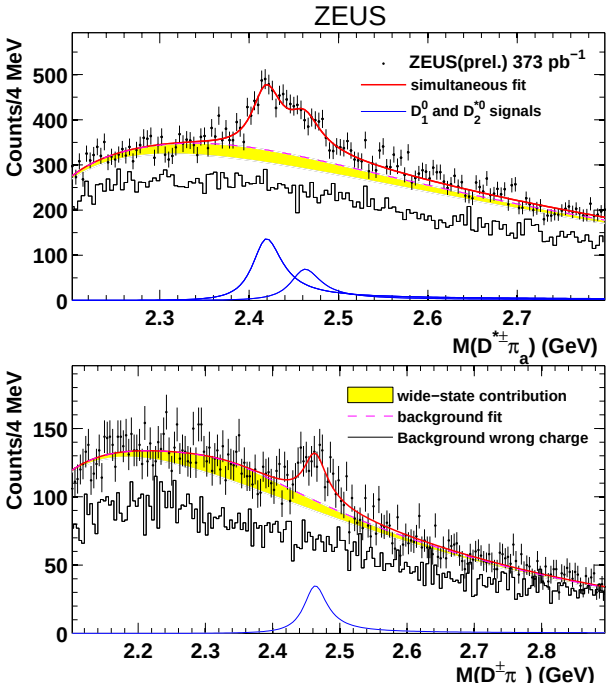

Figure 1: The mass distributions (dots) $M(D^{*\pm}\pi_a^{\mp})$ (upper plot) and $M(D^{\pm}\pi_a^{\mp})$ (lower plot). The histograms are the corresponding distributions for wrong-charge combinations. The solid curves are the result of a simultaneous fit to D_1^0 and D_2^{*0} (upper plot) and to D_2^{*0} (lower plot) plus background (dashes curves). Contributions from the wide states $D_1(2430)^0$ and $D_0^*(2400)^0$ are shown as shaded bands.

was fitted to the relativistic $D-$wave Breit-Wigner function [1]. Yields of the three signals, the D_1^0 and D_2^{*0} masses and the D_1^0 width and helicity, h, were free parameters of the fit. The D_2^{*0} width was fixed to the PDG value of 43 MeV [5] and $h(D_2^{*0})$ was fixed to the theoretical prediction $h(D_2^{*0}) = -1$ [2]. Contributions from the wide states $D_1(2430)^0$ and $D_0(2400)^0$ [3] were added, respectively, to the $M(D^{*\pm}\pi_a)$ and $M(D^{\pm}\pi_a)$ fit with shapes described as relativistic S-wave Breit-Wigner functions. Their masses and widths were set to the PDG values [3] and their yields were taken, respectively, as 1.0 and 1.7 times the narrow states D_1^0 and D_2^{*0} [1]. Systematic uncertainties of the measured values were estimated from variations of the selection cuts, fit ranges, background parametrisation, bin width of the fitted distributions and yields of the wide states.

The results of the simultaneous fit (masses, widths and helicity parameters) are given in Tab. 2 and Figs. 1, 2 (solid curves). The D_1^0 width, $\Gamma(D_1^0) = 43.4 \pm 6.2(stat.)^{+7.3}_{-10.4}(syst.)$ MeV, is above the PDG,2010 value [3] of 20.4 ± 1.7 MeV, consistent with the previous ZEUS result [1]. The D_1^0 helicity parameter, $h(D_1^0) = 3.5^{+1.6}_{-1.0}(stat.)^{+2.0}_{-0.8}(syst.)$, is consistent with the pure D-wave prediction of $h = 3$. The presented measurements can also be compared to new high precision results by BABAR [4]. Among other parameters, BABAR measured the D_1^0 width to be $\Gamma(D_1^0) = 31.4 \pm 0.5(stat.) \pm 1.3(syst.)$ MeV, which is also higher than the above-quoted PDG,2010 value [3] and has been included into new PDG averaging, PDG,2011 [3]. BABAR result agrees well with the old [1] and new ZEUS results.

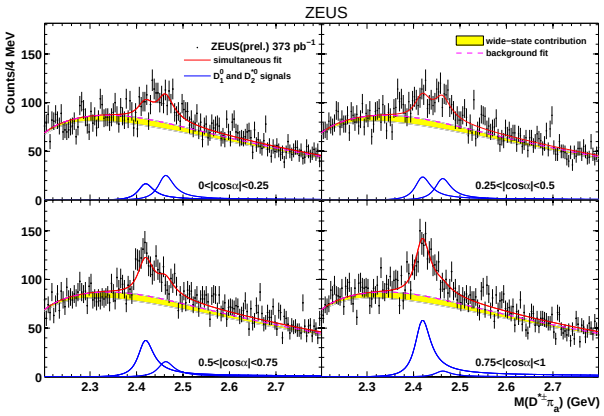

Figure 2: The mass distributions (dots) $M(D^{*\pm}\pi_a^{\mp})$ in four helicity bins. The solid curves are the result of a simultaneous fit to D_1^0 and D_2^{*0} plus background (dashes curves). Contributions from the wide states $D_1(2430)^0$ and $D_0^*(2400)^0$ are shown as shaded bands.

Parameter	HERAI [1]	HERAII	BABAR,2010 [4]	PDG,2010[3]	PDG,2011[3]
$M(D_1^0)$,MeV	$2420.5\pm2.1(stat)\pm0.9(syst)$	$2422.2\pm1.7(stat)^{+1.2}_{-2.8}(syst)$	$2420.1\pm0.1(stat)\pm0.8(syst)$	2422.0±0.6	2421.3±0.6
$\Gamma(D_1^0)$,MeV	$53.2\pm7.2(stat)^{+3.3}_{-4.9}(syst)$	$43.4\pm6.2(stat)^{+7.3}_{-10.4}(syst)$	$31.4\pm0.5(stat)\pm1.3(syst)$	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	$2469.1\pm3.7(stat)^{+1.2}_{-1.3}(syst)$	$2465.0\pm3.3(stat)^{+1.2}_{-2.9}(syst)$	$2462.2\pm0.1(stat)\pm0.8(syst)$	2462.8±1.0	2462.6±0.7
$\Gamma(D_2^{*0})$,MeV	$43(fixed)$	$43(fixed)$	$50.5\pm0.6(stat)\pm0.7(syst)$	42.9±3.1	49.0±1.4
$h(D_2^{*0})$	$-1(fixed)$	$-1(fixed)$	-1	–	–

Table 1: Results of the simultaneous fit of the D_1^0 and D_2^{*0} mesons.

3. Conclusions

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 theoretical expectations [2] and with published ZEUS results [1] 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 [4]. 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.

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