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Measurement of the D$^+$ Lifetime with the ZEUS Micro-Vertex Detector at HERA-II

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Abstract

The lifetime of the D^+ meson has been measured for the first time at HERA with the ZEUS Micro-Vertex Detector using an integrated luminosity of 91 pb^{-1}. The $D^\pm$ mesons have been reconstructed in the decay channel $D^+ \to K^-\pi^+\pi^+$ and the corresponding anti-particle decay. The D^+ lifetime has been obtained from a fit to the proper time distribution to be $\tau(D^+) = 1017 \pm 86\,(\text{stat.}) \pm 47\,(\text{syst.})$ fs.

1 Introduction

Production of $D^{\pm}$ mesons in $e^{\pm}p$ collisions has been extensively studied at HERA [1, 2]. In the H1 analysis, the $D^{\pm}$ signal has been enhanced with respect to the background by exploiting the large $D^{\pm}$ lifetime [3]. For the HERA-II run, the ZEUS detector has been upgraded with a silicon Micro-Vertex Detector (MVD) [4], thus enabling the experiment for the first time to resolve impact parameters and decay lengths of heavy flavor hadrons.

The ZEUS detector is described in detail elsewhere [5]. The major component of importance to this analysis is the MVD. The effective spatial resolution of the MVD depends critically on the achieved quality of the alignment. Beyond the information from a survey of the MVD sensors, the alignment is improved using reconstructed tracks in two steps: first with cosmic muons [6] and finally with tracks from ep collisions. The impact of this last step of track-based alignment is shown in Fig. 1, which displays the visible inclusive impact parameter resolution with respect to the beam spot for tracks with a transverse momentum[1] of $p_T > 3$ GeV and least two hits in both the Z and $R\phi$ views of the MVD barrel. This resolution includes the intrinsic size of the interaction region. The ep track alignment is found to improve the resolution considerably, in particular in the range of the sensors on both sides of the beam pipe, which are less accessible to alignment with cosmic muons.

2 Data Analysis

The data presented here have been collected in the e^-p run between December 2004 and September 2005 and correspond to an integrated luminosity of 91 pb^{-1}. Deep inelastic scattering (DIS) events have been selected requiring $Q^2 > 4\ GeV^2$, $E'_e > 8\ GeV$, $30 < E - P_z < 65\ GeV$ and $0.02 < y_e < 0.7$, where Q^2 is the virtuality of the exchanged photon, E'_e the energy of the scattered electron, E and P_z are the summed energy and longitudinal momentum of the event as determined by the calorimeter, and y_e is the relative electron energy loss in the proton rest frame.

The $D^{\pm}$ mesons have been reconstructed in the decay channel $D^+ \rightarrow K^-\pi^+\pi^+$ and the corresponding anti-particle decay[2]. Kaon and pion candidates have been selected as tracks with $p_T > 0.65$ GeV and $p_T > 0.45$ GeV, respectively, and a pseudorapidity of $|\eta| < 1.75$.

[1] The ZEUS coordinate system is a right-handed Cartesian system, with the Z axis pointing in the proton beam direction, and the X axis pointing left towards the centre of HERA. The coordinate origin is at the nominal interaction point.

[2] Hereafter, charge conjugation is implied.

Only tracks with at least two MVD hits in both the Z and $R\phi$ views of the barrel have been considered.

Candidates for D^+ mesons have been formed by selecting all combinations of one kaon and two pion candidates, with the pions having charges opposite to that of the kaon, which could be fitted to a common secondary vertex with $\chi^2_{vtx} < 4$. Only D^+ candidates with $p_T > 3$ GeV and $|\eta| < 1.5$ have been accepted. For each accepted D^+ candidate, the decay length in the plane transverse to the beam, l_{xy}, has been calculated as

$$l_{xy} = \frac{1}{\sqrt{p_x^2 + p_y^2}} \begin{pmatrix} p_x \\ p_y \end{pmatrix} \begin{pmatrix} X_{vtx} - X_{bsp} \\ Y_{vtx} - Y_{bsp} \end{pmatrix} \quad (1)$$

where p_x and p_y are the components of the transverse momentum of the D^+, X_{vtx} and Y_{vtx} are its vertex coordinates, and X_{bsp} and Y_{bsp} are the transverse coordinates of the beam spot, which have been determined by averaging primary vertex positions at run level. The decay length significance has been computed as $S_{l,xy} = l_{xy}/\sigma(l_{xy})$, where the error $\sigma(l_{xy})$ takes the resolutions of tracks and beam spot into account.

The invariant mass spectrum of the $K^-\pi^+\pi^+$ candidates with $S_{l,xy} > 5$ is shown in Fig. 2. The distribution has been fitted with the sum of a Gaussian and a linear background term. The fitted width corresponds to a mass resolution of 18 MeV. Displays of two typical events are shown in Fig. 3.

In order to measure the D^+ lifetime, the production rate has been analyzed in four intervals of the proper time ct, which has been reconstructed from the transverse decay length as

$$ct = \frac{m}{p_T}\, l_{xy} \quad (2)$$

where m is the invariant mass calculated for each $K^-\pi^+\pi^+$ combination. The resulting proper time distribution is shown in Fig. 4. The expected shape for this distribution has been modeled by convoluting the natural exponential lifetime spectrum with effects of Lorentz boost and resolution

$$\frac{dN}{d(ct)} \propto \int d(ct)_{true} \exp(-\frac{(ct)_{true}}{c\tau}) \int d(\frac{p_T}{m})\; g(\frac{p_T}{m})\; h\left(\frac{p_T}{m}\; (ct - (ct)_{true})\right) \quad (3)$$

where the shape of the $\frac{p_T}{m}$ spectrum, $g(\frac{p_T}{m})$, is taken from a study of D^0 mesons originating from $D^{*+} \to D^0\pi^+$ decays. The resolution function h has been assumed to be a Gaussian function, centered at zero with a width equal to a sum in quadrature of a decay length resolution of 160 μm, justified by Monte Carlo (MC), and the beam spot spread. The result from the fit of this function is $c\tau(D^+) = 305 \pm 26$ (stat.) $\pm$ 14 (syst.) μm, which corresponds to $\tau(D^+) = 1017 \pm 86$ (stat.) ± 47 (syst.) fs. These values contain a correction for the $b\bar{b}$ component which has been evaluated using MC. The systematic error covers effects from efficiency, a conservative variation of the decay length resolution and the uncertainty of the $b\bar{b}$ correction. The effect of the resolution is relatively small since the measurement has been carried out in the exponential regime of the ct range.

In Table 1, the result is compared to some other measurements of the D^+ lifetime, and the world average from the Particle Data Group [3], and is found to be in good agreement. Though determined by a collider experiment, the achieved accuracy is in a similar range as the results from the CERN SPS experiments [7, 8], though not competitive with the dedicated photo-production measurements at the FNAL Tevatron [10].

3 Conclusions

Using the ZEUS Micro-Vertex Detector, the lifetime of the D^+ meson has been measured in e^-p collisions at HERA as $\tau(D^+) = 1017 \pm 86$ (stat.)± 47 (syst.) fs. The value is in good agreement with other measurements of the D^+ lifetime. The measurement highlights the flavor-tagging capabilities of the ZEUS Micro-Vertex Detector with its recently improved alignment.

References

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	$\tau(D^+)$ (fs)
ZEUS (prel.) 05	$1017 \pm 86 \pm 47$
ACCMOR [7]	1050^{+77}_{-72}
NA14/2 [8]	$1030 \pm 80 \pm 60$
CLEO [9]	$1033.6 \pm 22.1^{+9.9}_{-12.7}$
FOCUS [10]	$1039.4 \pm 4.3 \pm 7.0$
World average [3]	1040 ± 7

Table 1: *The D^+ lifetime, $\tau(D^+)$.*

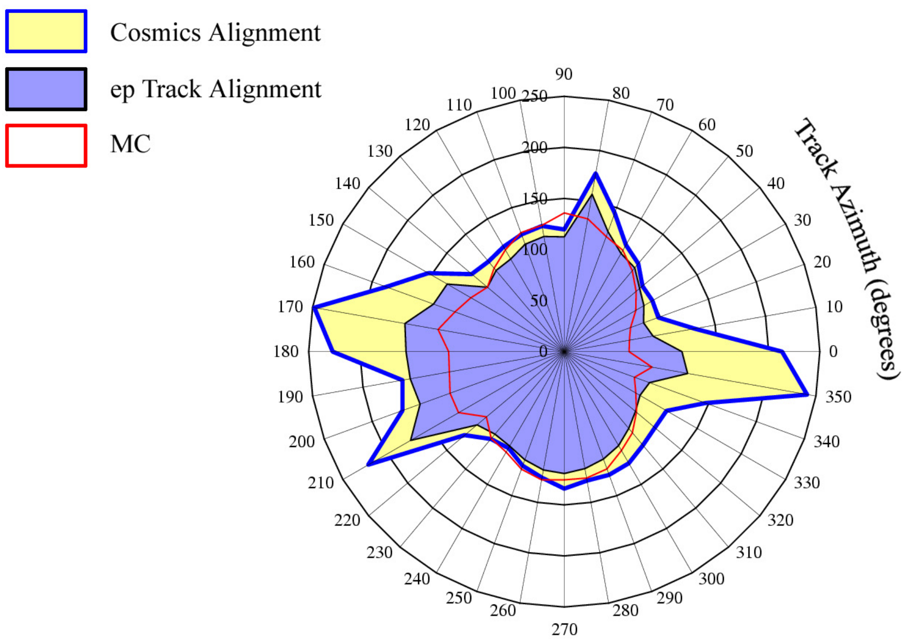

Figure 1: *Polar diagram illustrating the effect of alignment in the visible impact parameter resolution with respect to the beam spot as a function of azimuth angle, for tracks with* $p_T > 3$ *GeV. This resolution includes the intrinsic size of the interaction region, and is shown as the radial coordinate in units of* μm. *The light-shaded contour shows the resolution at the level of alignment with cosmic muons, the dark shade displays the improvement after an additional alignment step with tracks from ep collisions. The thin line without shade is the corresponding MC result, which does not simulate misalignment.*

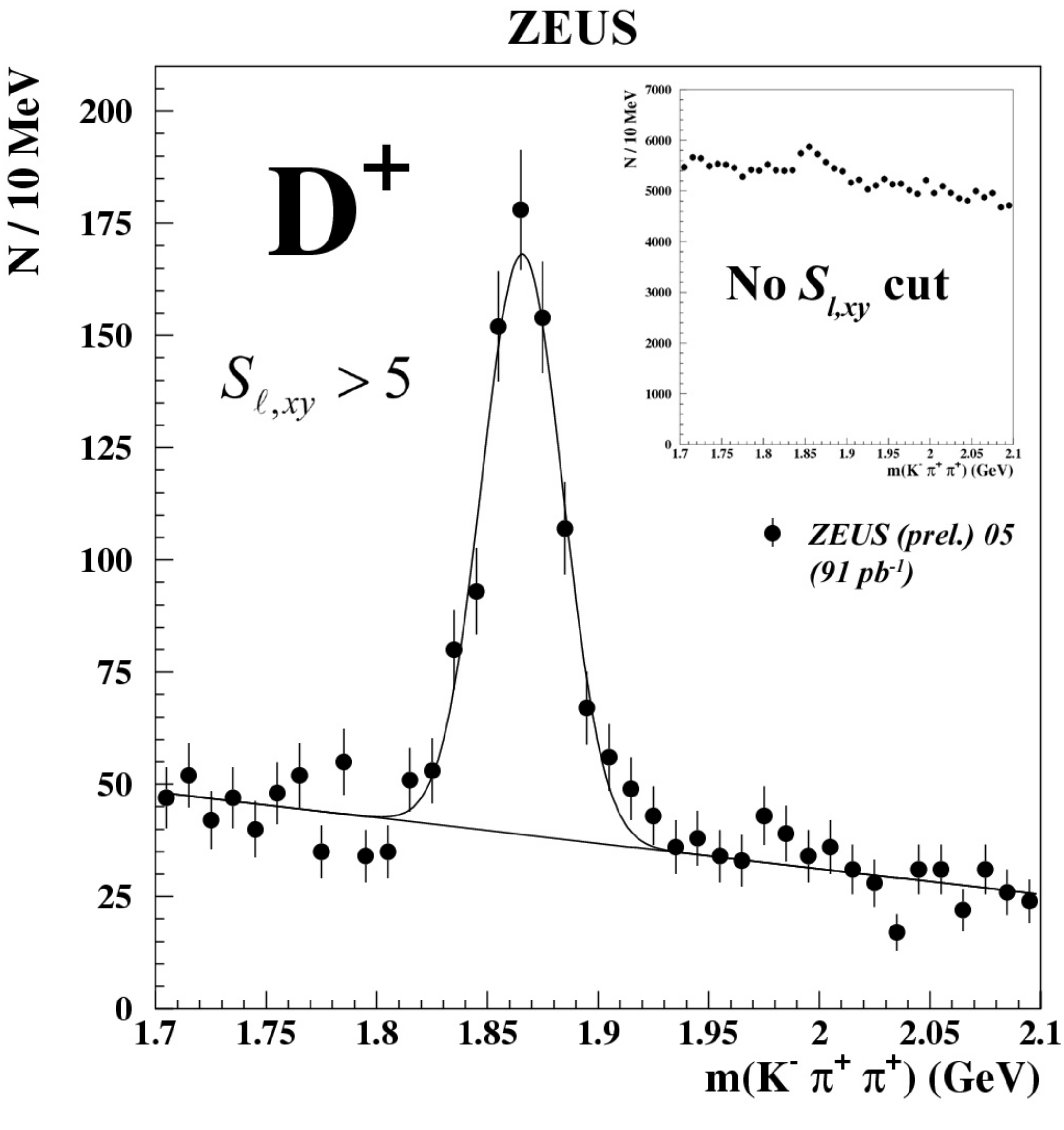

Figure 2: *The* $\mathrm{m}(\mathrm{K}^{-}\pi^{+}\pi^{+})$ *distribution for the* D^{+} *candidates with* $S_{l,xy} > 5$. *The solid curve represents a fit to a sum of a Gaussian function and a linear background, with the background part shown separately. The insert displays the corresponding distribution without any cut on* $S_{l,xy}$ *applied.*

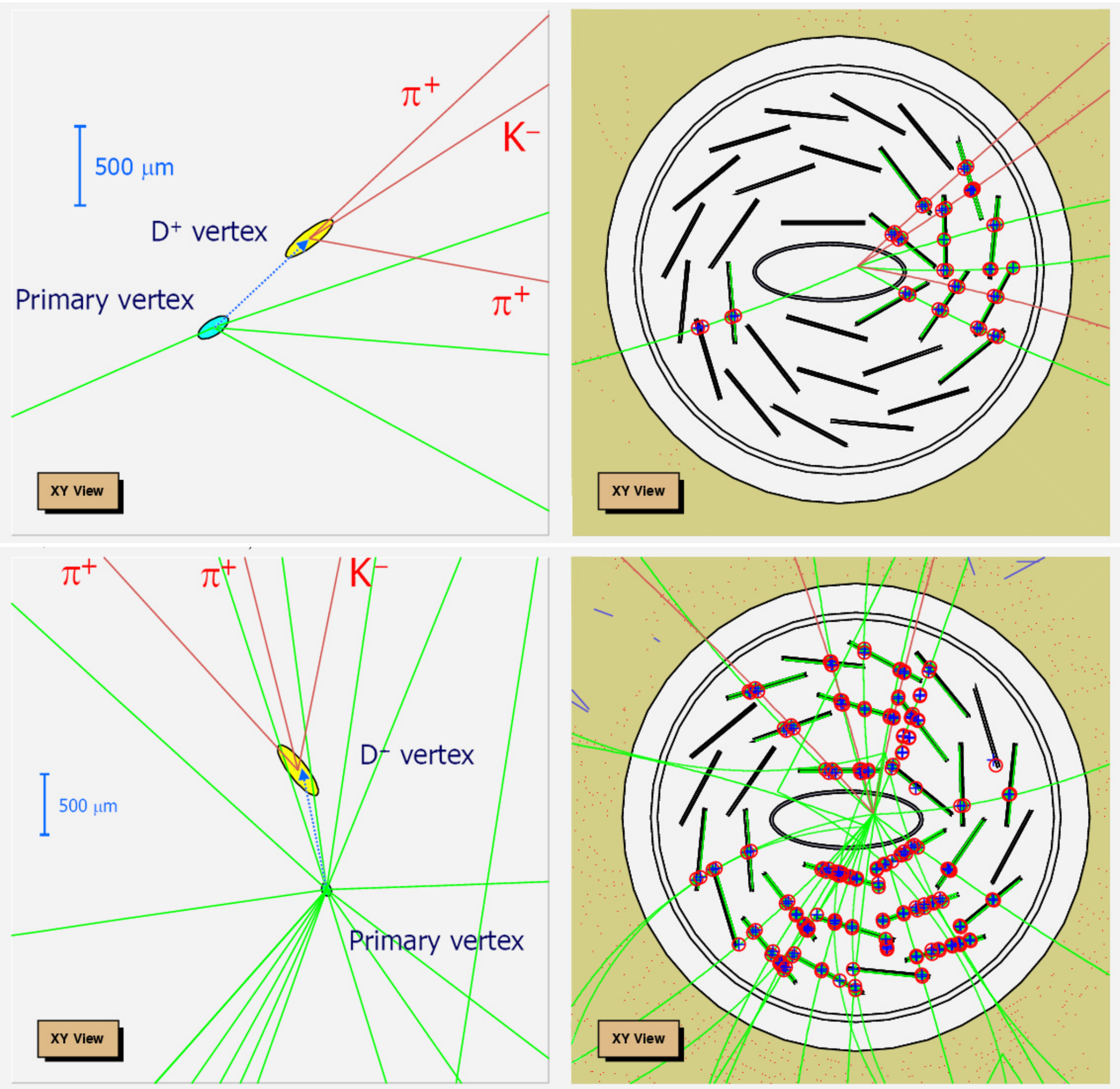

Figure 3: *Event displays with reconstructed $D^{\pm}$ candidates. The small ellipses in the enlarged section on the left-hand side represent the 1σ contours of primary and secondary vertex.*

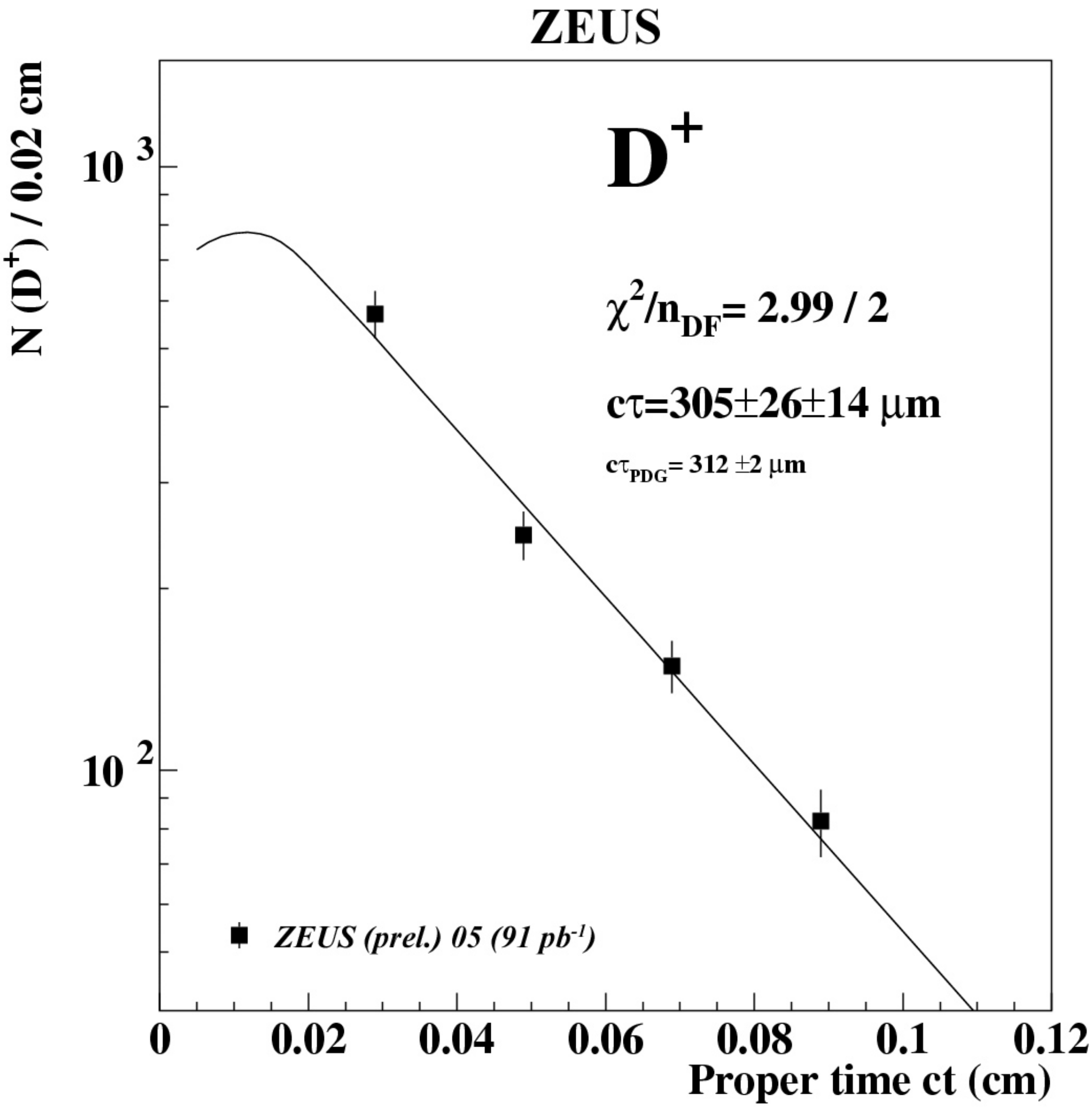

Figure 4: *Number of reconstructed D^+ mesons as a function of proper time, ct. The solid line is the result of the fit described in the text.*