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A study of the semileptonic decay $D^+ \to \bar{K}^{*0} e^+ \nu_e$

WA82 Collaboration

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The decay $D^+ \to K^- \pi^+ e^+ \nu_e$ has been studied by the hadroproduction experiment WA82. The decay is dominated by the $\bar{K}^{*0}$ (892) resonance. The ratio of branching ratios, $B(D^+ \to \bar{K}^{*0} e^+ \nu_e)/B(D^+ \to K^- \pi^+ \pi^+)$, is found to be $0.62 \pm 0.15 \pm 0.09$. The $\bar{K}^{*0}$ mesons have a ratio of longitudinal to transverse polarisation of $0.6 \pm 0.3^{+0.3}_{-0.1}$.

The semileptonic decays of charmed mesons provide information on the Cabibbo–Kobayashi–Maskawa (CKM) matrix elements which define the weak quark eigenstates. Previous studies of semileptonic decays of D mesons [1] have shown that for the D^0 and D^+ the semileptonic final states $K e \nu_e$ and $K^* e \nu_e$ dominate. In order to extract the CKM matrix elements from experimental data the transition form factors must be computed from theory which is easiest in the case of the pseudoscalar decay mode since here only one form factor is required. However, the only independent test of the calculation of the form factors comes from the more complicated vector final states. Necessary experimental input to test these calculations include the $D^+ \to \bar{K}^{*0} e^+ \nu_e$ branching ratio and the ratio of longitudinal to transverse polarisation of the $\bar{K}^{*0}$ mesons, the experimental determination of which are discussed below.

This paper studies the $K\pi e \nu_e$ channels where the e–K charge correlation implied by a Cabibbo allowed $c \to s e^+ \nu_e$ transition and a strong K^* (892) signal are used to isolate a sample of $D^+ \to \bar{K}^{*0} e^+ \nu_e$ plus charge conjugate decays. The data come from experiment WA82 which has been performed using the CERN Omega Spectrometer equipped with a silicon microvertex detector, using a 340 GeV/c π^- beam on a 1.2 mm thick target of silicon and tungsten. Charm candidates were selected on-line by choosing only those events where one track was missing the primary vertex by more than 100 μm. Details of the layout of the apparatus, the trigger conditions and the data processing have been given in previous publications [2]. The high precision on vertex determination obtained using the microvertex detector together with good electron identification from the electromagnetic calorimeter has made the observation of these charmed decay modes possible.

For this study we used events which had the main

[1] Deceased.

vertex in the target, a three-prong secondary vertex outside the target and separated from the primary vertex by a value larger than 6σ (where $\sigma=\sqrt{\sigma_{\rm pri}^2+\sigma_{\rm sec}^2}$ with $\langle\sigma_{\rm pri}\rangle=0.45$ mm and $\langle\sigma_{\rm sec}\rangle=0.55$ mm). This cut has been tuned so as to maximise the signal and signal to noise ratio for the decay $D^+\to K^-\pi^+\pi^+$. A three-prong vertex is required in which one of the like signed particles is identified as an electron by the electromagnetic calorimeter. In this analysis the electron identification efficiency is 75% and the probability that a pion is misidentified as an electron is 0.9%. One of the other two particles is required to be identified as a kaon by a ring image Čerenkov detector while the third is required to be compatible with being a pion. Combinations in which the kaon and electron have the opposite (same) charge are considered as signal (background) events.

Events in which a hadron could have been misidentified as an electron from the $D^+\to K^-\pi^+\pi^+$ or $D^+\to K^-K^+\pi^+$ decays are removed by cuts on the effective masses. The background events are reduced further by cutting on the difference between the measured impact parameter of the $K\pi e$ system at the primary vertex and the maximum allowed impact parameter which can be calculated since the line of flight of the D^+ is measured and the maximum transverse momentum of the missing ν_e can be calculated from the energy of the ν_e in the D^+ centre of mass. The difference in the impact parameters is required to be <40 μm and reduces the like signed K–e (background) events from 17 to 6 whilst the number of unlike signed K–e (signal) events decreases from 54 to 50.

Fig. 1 shows the resulting $K\pi$ effective mass spectrum for the 50 signal events where the six background events are shown shaded. The $K\pi$ effective mass spectrum for the same events is shown in fig. 2 where it can be seen that the decay under study is dominated by the $K^*(892)$ resonance. A fit to the $K\pi$ mass spectrum using a relativistic P-wave Breit–Wigner to describe the $K^*(892)$, whose mass and width have been fixed to the PDG value [3], plus an S-wave background yields a resonance fraction of 0.7 ± 0.2 which is consistent with the $K^*(892)$ dominance found by E691 [4] and Mark III [5].

The ratio of branching ratios $B(D^+\to\bar{K}^{*0}\,e^+\nu_e)/B(D^+\to K^-\pi^+\pi^+)$ has been calculated from the number of events in each decay mode after correcting for detector efficiencies, event reconstruction and the effect of cuts. This has been done by generating events including the decays $D^+\to\bar{K}^{*0}\,e^+\nu_e$ and $D^+\to K^-\pi^+\pi^+$ using the Lund generator [6]. These events have then been passed through a detector simulation program and the same trigger algorithm, filter algorithm, reconstruction and analysis programs used for the real data. The efficiency of the electromagnetic calorimeter has been determined using electron pairs from the real data. After correcting for

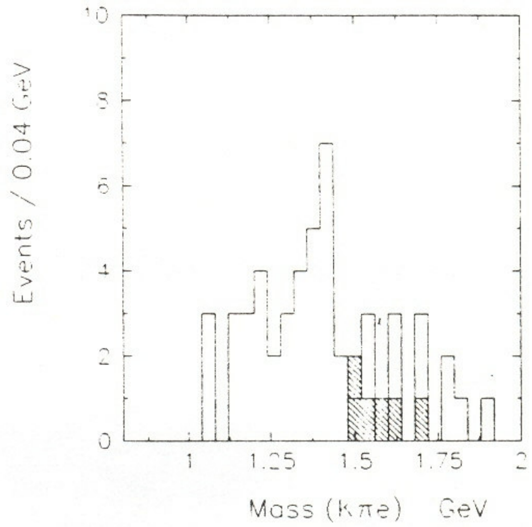

Fig. 1. The $K\pi e$ effective mass spectrum. The like-signed K–e (background) events are shown shaded.

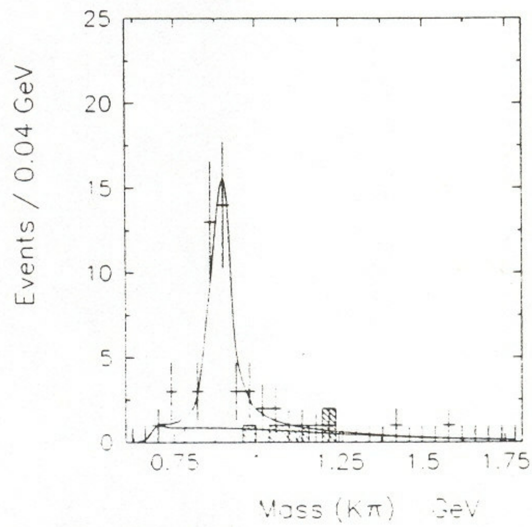

Fig. 2. The $K\pi$ spectrum. The like-signed K–e (background) events are shown shaded.

these efficiencies and acceptances and taking into account the unseen $\overline{K}^{*0}\to\overline{K}^0\pi^0$ decay mode we find

$$\frac{B(D^+\to\overline{K}^{*0}e^+\nu_e)}{B(D^+\to K^-\pi^+\pi^+)}$$

$$=0.62\pm0.15\text{ (stat.)}\pm0.09\text{ (syst.)}\,.$$

Using the Mark III value of $B(D^+\to K^-\pi^+\pi^+)=(9.1\pm1.3\pm0.4)\%$ [7], we obtain

$$B(D^+\to\overline{K}^{*0}e^+\nu_e)=(5.6\pm1.6\pm0.9)\%$$

consistent with the value of $(4.4\pm0.4\pm0.8)\%$ determined by E691 [4], with the value of $(5.3^{+1.9}_{-1.1}\pm0.6)\%$ by Mark III [5] and with the value of $(4.2\pm0.6\pm1.0)\%$ by ARGUS [8].

The decay $D^+\to\overline{K}^{*0}\,e^+\nu_e$ has been selected by requiring $0.84\leqslant m(K^\pm\pi^\mp)\leqslant0.94$ GeV. For these events, the $\cos\theta_K$ distribution, where θ_K is the helicity angle of the kaon in the K^* centre of mass has been calculated. The acceptance corrected normalised $\cos\theta_K$ distribution, where the acceptance for $|\cos\theta_K|\leqslant0.95$ varies smoothly and changes from 0.86% to 1.83% over this range, is shown in fig. 3. It has been fitted, by maximum likelihood, using the expression

$$\frac{dN}{d(\cos\theta_K)}\propto1+\left(2\frac{\Gamma_L}{\Gamma_T}-1\right)\cos^2\theta_K$$

and gives $\Gamma_L/\Gamma_T=0.6\pm0.3^{+0.3}_{-0.1}$, where the major contribution to the systematic error comes from considering the effect of removing events from the extreme values of $|\cos\theta_K|$ where the acceptance is less well known. This measurement is in agreement with the value obtained by Mark III of $0.5^{+1.0+0.1}_{-0.1-0.2}$ [5] and is consistent with theoretical predictions which range from 0.9 to 1.2 [9] but is smaller than the value of $1.8^{+0.6}_{-0.4}\pm0.3$ found by E691 [4].

In summary, we report on the observation of the decay $D^+\to K^-\pi^+e^+\nu_e$ which is dominated by the $\overline{K}^{*0}(892)$. The ratio of branching ratios, $B(D^+\to\overline{K}^{*0}e^+\nu_e)/B(D^+\to K^-\pi^+\pi^+)$, is found to be $0.62\pm0.15\pm0.09$. The $\overline{K}^{*0}$ mesons have a ratio of longitudinal to transverse polarisation of $0.6\pm0.3^{+0.3}_{-0.1}$.

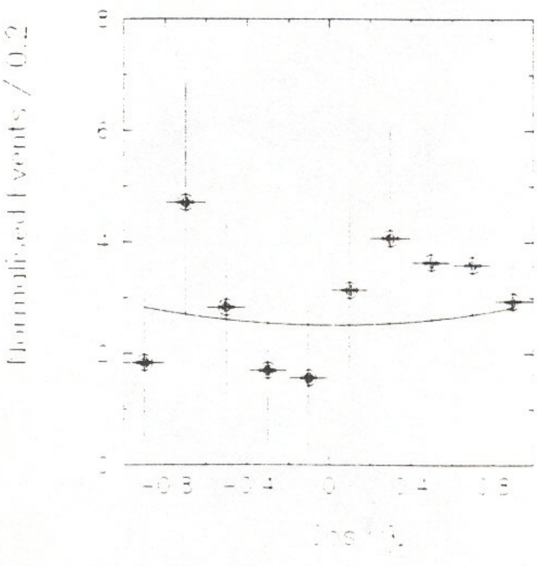

Fig. 3. The $\cos\theta_K$ distribution for the $D^+\to\overline{K}^{*0}\,e^+\nu_e$ plus charge conjugate decays. The fit is described in the text.

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