CHARGED D* PRODUCTION IN e^+e^--ANNIHILATION

JADE Collaboration

W. BARTEL, L. BECKER, C. BOWDERY [1], D. CORDS [2], R. FELST, D. HAIDT, H. JUNGE [3], G. KNIES, H. KREHBIEL, P. LAURIKAINEN [4], R. MEINKE, B. NAROSKA, J. OLSSON, E. PIETARINEN [4], D. SCHMIDT [3], P. STEFFEN [5], P. WARMING, M. ZACHARA
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

G. DIETRICH, E. ELSEN [2], G. HEINZELMANN, H. KADO, M. KUHLEN, T. MASHIMO, K. MEIER, A. PETERSEN, U. SCHNEEKLOTH, G. WEBER
II. Institut für Experimentalphysik der Universität Hamburg, Germany

K. AMBRUS, S. BETHKE, A. DIECKMANN, J. HEINTZE, K.H. HELLENBRAND, R.D. HEUER [5], S. KOMAMIYA, J. von KROGH, P. LENNERT, H. MATSUMURA, H. RIESEBERG, J. SPITZER, A. WAGNER
Physikalisches Institut der Universität Heidelberg, Germany

A. FINCH, F. FOSTER, G. HUGHES, T. NOZAKI, J. NYE
University of Lancaster, England

J. ALLISON, J. BAINES, A.H. BALL, R.J. BARLOW, J. CHRIN, I.P. DUERDOTH, T. GREENSHAW, P. HILL, F.K. LOEBINGER, A.A. MACBETH, H. McCANN, H.E. MILLS, P.G. MURPHY, P. ROWE, K. STEPHENS
University of Manchester, England

R.G. GLASSER, B. SECHI-ZORN, J.A.J. SKARD, S. WAGNER, G.T. ZORN
University of Maryland, MD, USA

S.L. CARTWRIGHT, D. CLARKE, R. MARSHALL, J.B. WHITTAKER
Rutherford Appleton Laboratory, Chilton, England

and

J. KANZAKI, T. KAWAMOTO, T. KOBAYASHI, M. KOSHIBA, M. MINOWA, M. NOZAKI, S. ORITO, A. SATO, H. TAKEDA, T. TAKESHITA, Y. TOTSUKA and S. YAMADA
Laboratory of International Collaboration on Elementary Particle Physics and Department of Physics, University of Tokyo, Japan

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[1] European Science Exchange Fellow.
[2] Present address: SLAC, CA, USA.
[3] Universität-Gesamthochschule Wuppertal, Germany.
[4] University Helsinki, Helsinki, Finland.
[5] Present address: CERN, Geneva, Switzerland.

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The inclusive production of $D^{*\pm}$ mesons in e^+e^--annihilations at $\sqrt{s} \sim 34.4$ GeV is investigated with the JADE detector at PETRA. $D^{*\pm}$ mesons are reconstructed through their decay into D mesons resulting in $(K\pi)\pi$ and $(K3\pi)\pi$ final states. The measured differential cross section is compatible with a hard c quark fragmentation. The $D^{*\pm}$ production angular distribution shows a charge asymmetry of $A = -0.14 \pm 0.09$ which is in agreement with the expectation from the weak–electromagnetic interference effect in the standard model. Global properties of $D^{*\pm}$ events are seen to be similar to average multihadronic event properties.

The inclusive production of charged D^* mesons in e^+e^--annihilation has been studied by various experiments [1–5]. At PETRA energies the charmed hadrons contain mainly the primary charm quark from $e^+e^- \to c\bar{c}$. Therefore, the study of $D^{*\pm}$ mesons provides information on the c quark fragmentation. Further, it is possible to investigate weak–electromagnetic interference effects in quark production using the angular distribution of produced D^*'s. The expected charge asymmetry is larger than for leptons (due to the c quark charge of 2/3). In this way, constraints on the weak isospin of the charm quark are obtained.

In the experiment reported here the JADE detector at the DESY storage ring PETRA was used. The data were taken during 1979–1982 at centre of mass energies in the range between 29.9 GeV and 38.7 GeV with an average energy of $\sqrt{s} \sim 34.4$ GeV corresponding to an integrated luminosity of $\int L\, dt = 74.7\ \mathrm{pb}^{-1}$. 23 923 annihilation events with multihadronic final states were selected by a method described in a previous publication [6].

In this analysis only charged particles coming from the primary vertex were used. In order to improve the momentum resolution the average e^+e^- interaction vertex was included in constrained track fitting.

The charged D^*'s were identified using the decay

$$D^{*+} \to D^0\pi^+ \qquad (1)$$

(here and in the following we omit to write the charge conjugate mode). Due to the special decay kinematics a D^* signal shows up better in the distribution of the mass difference

$$\Delta M = M(D^0\pi^+) - M(D^0) \qquad (2)$$

than in the mass distribution $M(D^0\pi^+)$ itself [7].

The D^0 meson was studied in the two decay modes:

$$D^0 \to K^-\pi^+ , \qquad (3)$$

$$\to K^-\pi^+\pi^-\pi^+ . \qquad (4)$$

The masses $M(K^-\pi^+)$ and $M(K^-\pi^+\pi^-\pi^+)$ were calculated using every charged track with a momentum $p > 1$ GeV/c applying both the π and the K mass hypothesis. These mass distributions have no obvious structure in the D^0 region. In accordance with the experimental mass resolution (as obtained by Monte Carlo calculations) the D^0 mass interval was assumed to be

$$1.66 < M(D^0) < 2.06\ \mathrm{GeV}. \qquad (5)$$

To form a D^{*+}, these D^0 candidates were combined with an additional charged track (without momentum cut) using the pion mass hypothesis.

Analysing the D^{*+} production in terms of its fractional energy x a clear signal is seen only for

$$x = E_{D^*}/E_{\mathrm{beam}} > 0.4 . \qquad (6)$$

Figs. 1a, 1b show the distribution of the mass difference (2) for the two D^0 decay modes (3) and (4) for the above cut in x. A clear enhancement around

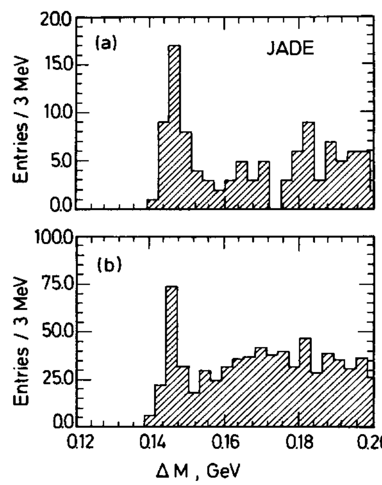

Fig. 1. (a) Distribution of $\Delta M = M(D^0\pi^+) - M(D^0)$ where D^0 is the $(K^-\pi^+)$ system in the mass interval $1.66 < M(D^0) < 2.06$ GeV. (b) Distribution of $\Delta M = M(D^0\pi^+) - M(D^0)$ where D^0 is the $(K^-\pi^+\pi^-\pi^+)$ system in the mass interval $1.66 < M(D^0) < 2.06$ GeV.

ΔM = 145 MeV is seen corresponding to the decay of the D^{*+} meson. The width is consistent with the experimental mass resolution as obtained from Monte Carlo calculations. Therefore, the "signal" event sample was defined by

$$\Delta M < 0.156 \text{ GeV}, \tag{7}$$

resulting in 40 and 52 events for the decay modes (3) and (4), respectively.

The peak structure in ΔM vanishes if instead of (5) the mass interval $2.06 < M(K^-\pi^+), M(K^-\pi^+\pi^-\pi^+) < 2.46$ is used. For the decay mode (3) the low mass region $M(K^-\pi^+) < 1.66$ cannot be used as a control region because around $M(K^-\pi^+) \sim 1.62$ a reflection of the decay modes

$$D^0 \to K^-\rho^+ \to K^-\pi^+\pi^0, \tag{8}$$

$$\to K^{*-}\pi^+ \to K^-\pi^0\pi^+ \tag{9}$$

is present [8]. The experimental mass resolution together with low statistics does not allow a separation between this reflection and the D^0 signal.

The acceptance was calculated using the Lund Monte-Carlo program [9] as an event generator for charged D^*'s including initial state radiation effects. These events were processed by routines which determined the trajectory of each particle through the JADE detector and which took into account the energy loss and resolution of the apparatus. The simulated events were then subjected to the same analysis as the real data so that the acceptance and mass resolution could be determined. The acceptance (including all cuts applied) is ~25% and ~6% for the decay modes (3) and (4), respectively.

It is observed that all events corresponding to decay channel (4) have more than one combination per jet satisfying the D^* criteria. Assuming no contribution from the charmed sea, only one charmed meson per jet should occur. Thus, for each combination a weight $w_i = 1/N_{\text{comb}}$ was introduced with $\Sigma_{\text{jet}} w_i = 1$. The branching ratios used are [10] $B(D^{*+} \to D^0\pi^+) = (44 \pm 10)\%$, $B(D^0 \to K^-\pi^+) = (3.0 \pm 0.6)\%$ and $B(D^0 \to K^-\pi^+\pi^-\pi^+) = (8.5 \pm 2.1)\%$.

For each x bin (with a bin width of 0.12) a background subtraction has been performed assuming a background of the form $dN/d(\Delta M) \sim (\Delta M - m_\pi)^\alpha$, α = 0.25–0.5 according to Monte Carlo calculations. In the region $x < 0.4$ no D^* signal can be seen in our data.

The data of the decay channels (3) and (4) were combined and the resulting differential cross section $s\,d\sigma/dx$ is given in fig. 2. This result is compatible with data given by MARK II, DELCO, HRS and TASSO [1–4]. The data indicate a hard c quark fragmentation. (For $x > 0.4$ an average value of $\langle x \rangle = 0.64 \pm 0.05$ is obtained.) The observed x dependence is different from x distributions for charged particles, K^0 mesons etc. [11] yielding an average x value around 0.1. A fit to the D^* differential cross section was made using a functional form proposed by Peterson et al. [11]

$$s\,d\sigma/dx \sim (1/x)[1 - 1/x - \epsilon/(1-x)]^{-2}. \tag{10}$$

For the parameter ϵ a value of 0.24 ± 0.08 was obtained corresponding to the curve shown in fig. 2.

It should be pointed out that due to initial state photon radiation and gluon emission the fractional energy x becomes smaller than the primordial fraction $z = E_{\text{hadron}}/E_{\text{quark}}$. Monte Carlo studies at $\sqrt{s}$ = 34 GeV in second order QCD show that the average value $\langle x \rangle$ of D^* mesons is about 16% lower than the average $\langle z \rangle$ in the primordial fragmentation process. (Initial state radiation contributes 5% and gluon emission, 11%.)

The integration over the experimentally measured points gives a cross section of $\sigma_{D^{*\pm}}(x > 0.4) = 0.14 \pm 0.02 \pm 0.03$ nb corresponding to

$$R_{D^{*\pm}}(x > 0.4) \equiv (\sigma_{D^{*+}} + \sigma_{D^{*-}})/\sigma_{\mu\mu}$$

$$= 1.9 \pm 0.3 \pm 0.4. \tag{11}$$

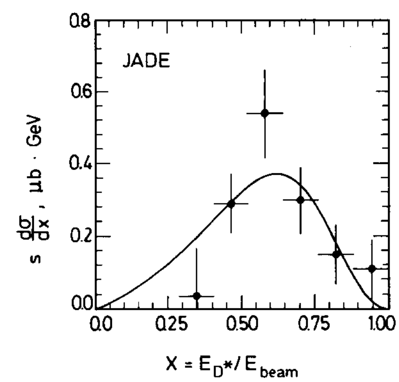

Fig. 2. Scaled differential cross section $s\,d\sigma/dx$ of the inclusive $D^{*\pm}$ meson production together with the Peterson fragmentation function fitted to our data.

This has to be compared with the theoretical value $R_{c,\bar{c}} \simeq 2.8$ (without x cut) indicating that the majority of produced charm quarks fragment via D^* mesons.

To estimate the number of D^* mesons coming from bottom hadrons the distributions of the masses $M(D^{*+}, \pi^-)$ and $M(D^{*+}, \pi^-, \pi^-)$ were analysed using the 92 charged D^* events. An upper limit of 8% was estimated for D^{*+} coming from $\bar{B}^0$ and B^- mesons.

The measurement of the D^{*+} production angular distribution $d\sigma/d\cos\theta$ (θ is the angle between the incoming electron e^- and the D^{*+}) can be used to measure the weak–electromagnetic interference. Assuming that the D^* mesons contain the primary c quark, $d\sigma/d\cos\theta$ measures the process $e^+e^- \to c\bar{c}$ since for large momenta ($x > 0.4$) the D^* direction is close to the c quark direction. The weak–electromagnetic interference leads to

$$d\sigma/d\cos\theta \sim 1 + \tfrac{8}{3}A\cos\theta + \cos^2\theta\ , \qquad (12)$$

where A is the forward–backward asymmetry which is given for $s \ll m_Z^2$ and neglecting terms $O(G_F^2)$ by the following expression

$$A = \tfrac{3}{2}(g_A^e g_A^c/e_c)(G_F/2\sqrt{2}\pi\alpha)\, s m_Z^2/(m_Z^2 - s)\ , \qquad (13)$$

Here, g_A^e, g_A^c are the axial vector coupling constants, predicted to be $-1/2$, $1/2$ in the standard model [13]. $e_c = 2/3$ is the c quark charge, G_F the Fermi coupling constant and m_Z the Z^0 mass. For $\sqrt{s} = 34.4$ $A = -0.14$ is expected.

For the calculation of the $\cos\theta$ distribution the data of the decay channels (3) and (4) (with weights) were combined. To improve the statistics we enlarged the $M(K^-\pi^+)$ mass interval to $1.50 < M(K^-\pi^+) < 2.06$ in order to take into account also events corresponding to the decay channels (8) and (9), which contain primary c quarks as well.

The resulting D^{*+} angular distribution is given in fig. 3. A fit of the data to the expression (12) yields $A = -0.14 \pm 0.09$. In principle, this result has to be corrected for D^* mesons coming from bottom hadrons and higher order QED terms but these effects can be neglected compared with the statistical error.

Using eq. (13) and $g_A^e = -1/2$, the result of the asymmetry measurement can be written as

$$g_A^c = T_{3L} = 0.50 \pm 0.32\ , \qquad (14)$$

where T_{3L} is the third component of the weak isospin of the left-handed charm quark. Note that the result

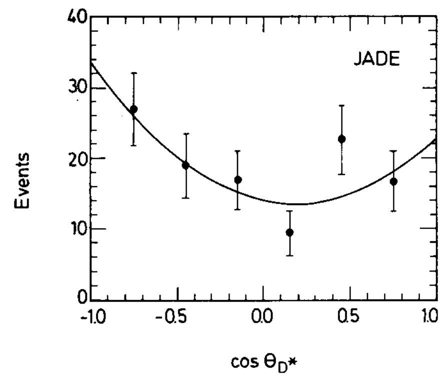

Fig. 3. Production angular distribution of $D^{*\pm}$ mesons together with the predicted function fitted to our data.

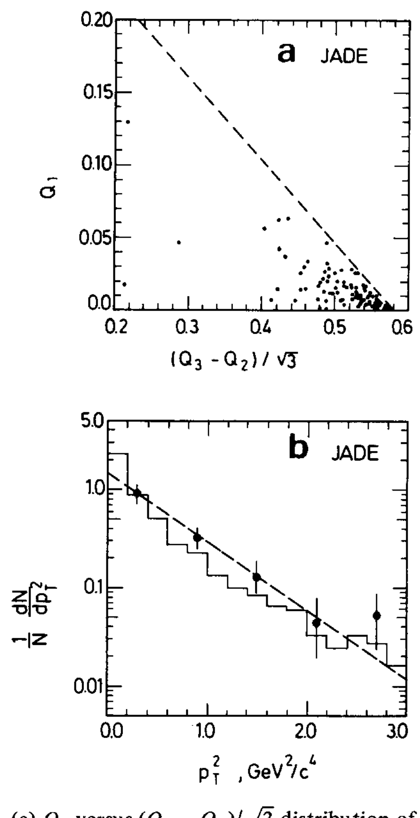

Fig. 4. (a) Q_1 versus $(Q_3 - Q_2)/\sqrt{3}$ distribution of events with a charged D^* meson. (b) Normalized p_T^2 distribution of the $D^{*\pm}$ mesons with respect to the sphericity axis (circles) together with the p_T^2 distribution for charged particles (histogram). The straight line shows an exponential function fitted to the $D^{*\pm}$ distribution.

(14) is compatible with a left-handed charm quark doublet ($T_{3L} = 1/2$).

To study the global properties of the D* event sample [4], the eigenvalues Q_i ($i = 1,2,3$) of the normalized sphericity tensor [14] were used. In fig. 4a the plot Q_1 versus $(Q_3 - Q_2)/\sqrt{3}$ is given for the combination of decay channels (3) – including parts of (8), (9) – and (4). This plot can be divided into 3 regions [15] corresponding to:

Region I.
two-jet events: $Q_3 > 0.9$.

Region II.
flat events (three-jet): $Q_3 < 0.9, Q_1 < 0.06$.

Region III.
spherical events: $Q_3 < 0.9, Q_1 > 0.06$.

It can be seen that the majority of the events belongs to the two-jet ($c\bar{c}$) class. Computing the fraction of planar (three-jet) events, $r = N_{II}/(N_I + N_{II} + N_{III})$, we get $r = (13 \pm 4)\%$ for the D^{*+} events. This number can be reproduced by Lund Monte Carlo calculations yielding an estimate of the strong coupling constant for charm quarks of $\alpha_s = 0.13 \pm 0.08$. Further, the ratio r can be compared with the value $r_{all} = (10 \pm 1)\%$ which has been calculated for multihadronic events with at least one charged track with $x > 0.4$. We conclude that the fraction of events with a hard gluon is (within the large errors) equal for charm events and events with other primary quarks. Similar conclusions have been reached in ref. [16].

Using the same events which entered into the Q plot of fig. 4a the p_T^2 distribution with respect to the sphericity axis was calculated. In fig. 4b this distribution is given (circles) together with the analogous distribution for charged particles with $x > 0.4$ (histogram). Fitting the D* distribution with an exponential function $\exp(-p_T^2/a^2)$ yields $a^2 = \langle p_T^2 \rangle = 0.62 \pm 0.08$ (dashed line in fig. 4b). Doing the same fit for charged particles and lambdas with $x > 0.4$, one gets $\langle p_T^2 \rangle_{charged} = 0.52 \pm 0.05$, $\langle p_T^2 \rangle_{lambda} = 0.56 \pm 0.07$, i.e. within the errors these values are compatible with the $\langle p_T^2 \rangle$ value of the D* events.

In conclusion, this experiment has observed charged D* production in the $(K\pi)\pi$ and $(K3\pi)\pi$ decay modes. The differential cross section $s\, d\sigma/dx$ indicates hard c quark fragmentation. From $R_{D^{*\pm}} = 1.9 \pm 0.3 \pm 0.4$ it is inferred that a large fraction of charm quarks fragments into D*'s. A forward–backward asymmetry of $A = -0.14 \pm 0.09$ is measured in agreement with the prediction of the standard model. Global properties of events containing a charged D* are similar to average multihadronic event properties, especially the fraction of events with a hard gluon is the same for both within the errors.

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