Inclusive Electron Production in Multiprong Events Produced by e^+e^- Annihilation

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We have measured inclusive electron production in multiprong events produced by e^+e^- annihilation in the center-of-mass energy range 3.9–7.4 GeV. We find the electron momentum spectra are consistent with the electrons coming mainly from decays of charmed particles, with a smaller contribution from decays of the τ lepton. From our data we calculate the average branching ratio for charmed particles to decay into an electron plus additional particles to be $(8.2 \pm 1.9)\%$.

We report on a measurement of inclusive electron production in events with three or more detected charged particles (multiprong events) produced by e^+e^- annihilation in the center-of-mass energy $(E_{c.m.})$ interval 3.9–7.4 GeV. Previous measurements[1-8] of anomalous electron and muon production in e^+e^- collisions have established the existence of new phenomena which can be interpreted as evidence for the production and decay of charmed particles and the τ lepton.[1] In this paper, we present measurements of inclusive electron production up to the highest center-of-mass energies presently available, and, with reasonable assumptions, obtain a value for the average branching ratio of charmed particles into an electron plus additional particles.

Since charmed-particle events are expected to appear mainly in the multiprong-event category and heavy-lepton events in the two-prong category,[9] we have separately analyzed the multiprong and two-prong events in our data to obtain a first-order separation of charm and heavy-lepton

events. Our analysis of the two-prong sample[2] shows an electron signal which is consistent with the heavy-lepton hypothesis. We report here on the analysis of the multiprong event sample.

The data used in this analysis were obtained at SPEAR in the $E_{c.m.}$ range 3.9–7.4 GeV, with a total time-integrated luminosity of 11.9 pb^{-1}. The measurements were made using the SLAC-LBL (Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory) magnetic detector,[10] with the addition of a 0.69-sr lead-glass electron-photon detector (called the LGW).[11] For our multiprong event sample we require that an electron with momentum greater than 300 MeV/c enter the LGW, and that two or more additional charged particles be observed in the magnetic detector. Further selection criteria were used to remove from our data sample purely electrodynamic reactions such as $e^+e^- \rightarrow e^+e^-\gamma$ with the γ converting to an e^+e^- pair.

The identification of electrons in the LGW and the determination of the background due to hadron

misidentification, photon conversion, Dalitz decay, and pion and kaon decay have been described previously.[6] Essentially, the background is first measured at the $\psi(3095)$ where we assume there is no anomalous electron production, and is then extrapolated to higher center-of-mass energies. We calculate that the background levels at the higher energies are the same as at the $\psi(3095)$ to within 25%.

In Table I we give the number of observed multiprong events with an electron candidate in the LGW for three $E_{c.m.}$ intervals. We also list the expected number of background events. We find a total inclusive electron signal of 293 ± 23 events. We correct the observed electron signal for solid angle (0.055) and momentum-dependent identification efficiency (~ 0.7) of the LGW; for tracking and track selection efficiency (0.77); and for the trigger efficiency and acceptance for the additional prongs (0.83). The cross section, $\sigma_e(p > 300$ MeV/$c)$, for the production of an electron of momentum greater than 300 MeV/c in multiprong events in each energy range is given in Table I. We divide this cross section by the theoretical cross section for muon pair production, $\sigma_{\mu\mu}$, to obtain $R_e(p > 300$ MeV/$c) = \sigma_e(p > 300$ MeV/$c)/\sigma_{\mu\mu}$, which we plot in Fig. 1 for finer energy intervals in the $E_{c.m.}$ range 3.9–7.4 GeV, along with our previously published[6] points in the $\psi(3772)$ region. An estimated 10% overall systematic error has not been included for the points given in Fig. 1. In addition to the enhancement at the $\psi(3772)$ we observe a threshold behavior in the 3.9–4.1-GeV region where many charm-production channels are opening, such as $e^+e^- \to D\bar{D}^*$ and $e^+e^- \to D^*\bar{D}^*$.[12] For $E_{c.m.} \geq 4.5$ GeV we find the rate for inclusive electron production in multiprong events, with electron momenta greater than 300 MeV/c, to be consistent with a constant level of 0.3–0.4 times the rate for $e^+e^- \to \mu^+\mu^-$.

Electron momentum distributions obtained for each of the three coarse $E_{c.m.}$ intervals are shown in Fig. 2. We observe that the spectra are soft with only about 5% of the observed electrons having momenta greater than half the beam energy. In this respect these spectra are similar to the previously observed[6] electron momentum spectrum from the semileptonic decay of D mesons produced in the decay of the $\psi(3772)$.

We calculate the τ contribution to the observed electron events using a point production cross section for a 1.8-GeV lepton,[8] an average of the measured values of the τ branching fraction into electrons,[1-3,5,8] $B(\tau^- \to e^-\nu_\tau\bar{\nu}_e) = (18 \pm 2)\%$, and an estimated τ branching fraction into multiprongs,[13] $B(\tau^- \to \nu_\tau + \geq 3$ charged prongs$) = (25 \pm 10)\%$. The calculated contribution of the τ to the observed electron production cross section and momentum spectra, assuming a $V - A$ coupling and a massless τ neutrino, are shown in Figs. 1 and 2, respectively. We note that all of the events with an electron of momentum greater than half the beam energy are consistent with coming from the τ. We calculate the τ contribution to the observed signal to be about 25%.

We compare the data to electron momentum spectra from D meson production and decay using the charmed-particle production models: $D^*\bar{D}^*$
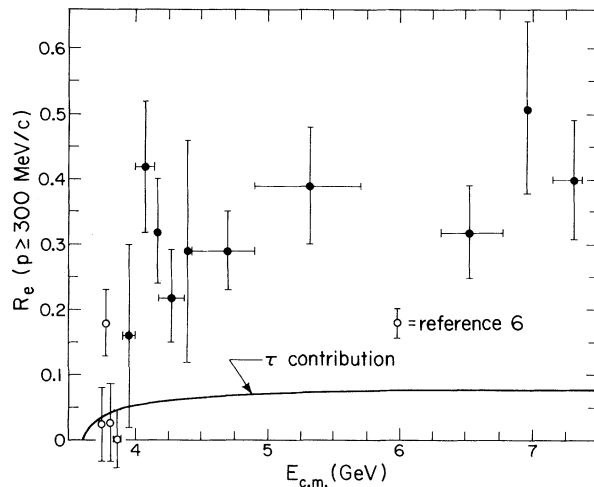
TABLE I. Time-integrated luminosity, number of electron candidates, expected number of background events, and the measured cross section for inclusive electron production in multiprong events for three $E_{c.m.}$ intervals.

$E_{c.m.}$ (GeV)	$\int L\,dt$ (pb^{-1})	N_{cand}	N_{bkgnd}^{expt}	$\sigma_e(p > 300$ MeV/$c)$ (nb)
3.90–4.44	2.81	142	48 ± 4.2	1.49 ± 0.28
4.44–5.71	3.29	138	46 ± 4.3	1.17 ± 0.22
6.31–7.38	5.80	168	61 ± 5.8	0.69 ± 0.13

FIG. 1. The ratio of the cross section for inclusive electron production with electron momenta greater than 300 MeV/c in multiprong events to the cross section for $e^+e^- \to \mu^+\mu^-$ vs the center-of-mass energy. The curve is an estimate of the contribution due to the process $e^+e^- \to \tau^+\tau^-$ with $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$ and $\tau^- \to \nu_\tau + \geq 3$ charged particles (plus charge conjugate), as described in the text.
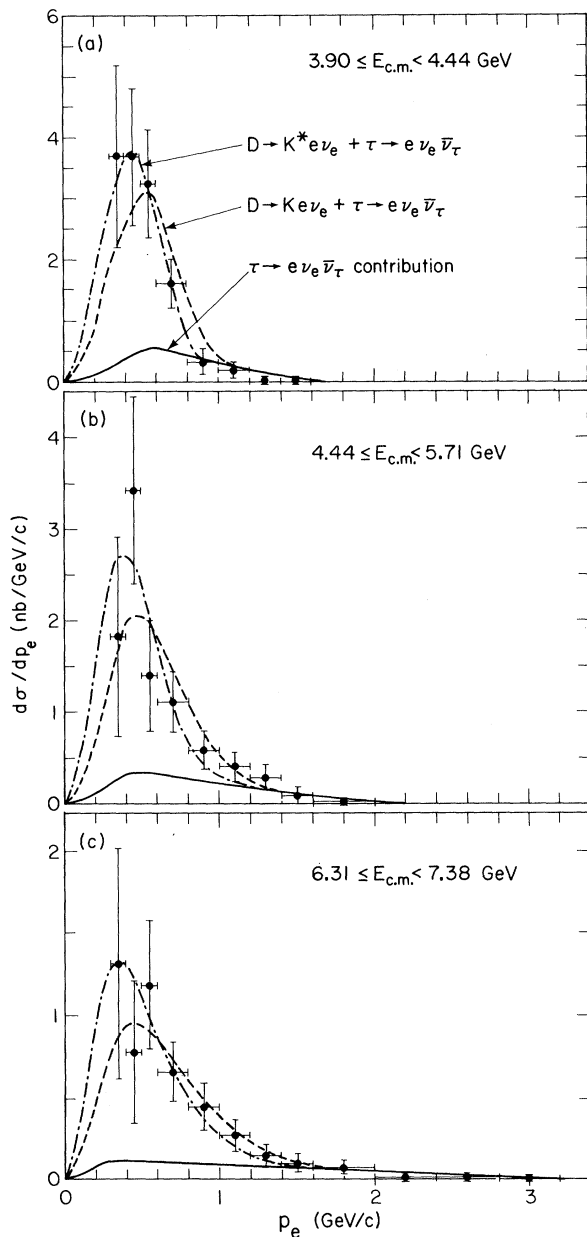
FIG. 2. The momenta spectra above 300 MeV/c for electrons produced in multiprong events in the three $E_{c.m.}$ intervals listed in Table I. The curves show the electron spectra expected from τ lepton production and decay, and from D meson production followed by the semileptonic decays $D \to K e \nu_e$ or $K^* e \nu_e$, as described in the text.

for $3.9 \le E_{c.m.} < 4.44$ GeV; $D^* \bar{D}^* \pi$ for $4.44 \le E_{c.m.} < 5.71$ GeV, and $D^* \bar{D}^* \pi \pi$ for $6.31 \le E_{c.m.} < 7.38$ GeV. We calculate electron momentum spectra assuming D meson decay into $K e \nu_e$ and $K^* e \nu_e$.[14] In Fig. 2 we show the predicted spectra from D decay added to the electron spectra from τ decay

with the D contribution normalized so that the sum equals the observed cross section above 300 MeV/c. We find reasonable agreement and conclude that the observed electron events are consistent with coming mainly from charmed-particle production and decay. We do not attempt to distinguish between different decay modes of the D meson because of uncertainties in the D production models and in the production of other charmed particles.

We attribute the events in excess of the expected τ contribution to charmed-particle production and derive an average charmed-particle branching ratio into an electron plus additional particles, $B(C \to eX)$, where the average extends over charmed meson and baryon production in a mixture obtained in $e^+ e^-$ annihilation. We write $B(C \to eX)$ $= \sigma_C(e)/2\sigma$ (charm) where $\sigma_C(e)$ is the corrected charm contribution to $\sigma_e(p > 300$ MeV/c) and σ (charm) is the cross section for the production of a pair of charmed particles.

To evaluate $\sigma_C(e)$ we subtract the τ contribution from our measured electron production cross section and correct for (1) the part of the electron momentum spectra below 300 MeV/c, and (2) the fraction of charm events with an electron and only one additional charged particle produced. To estimate (1) we average corrections calculated assuming the decay modes $D \to K e \nu_e$ and $D \to K^* e \nu_e$, which give corrections of 15% and 25%, respectively. We find correction (1) changes by only a few percent for different D production models. Correction (2) is determined from the observed multiplicity distribution of the detected events under the assumption that the produced multiplicity distribution for charmed-particle events is a smooth function, and is calculated to be approximately 5%.

To obtain an estimate of σ(charm) as a function of $E_{c.m.}$ above threshold, we use values of the total hadronic cross section measured at SPEAR in this experiment and subtract (a) the τ production cross section, and (b) the level of hadronic production below charm threshold (about 2.5 times $\sigma_{\mu\mu}$). The value of σ(charm) for $E_{c.m.} \ge 4.5$ GeV obtained in this way is about 2 times $\sigma_{\mu\mu}$.

In Fig. 3 we plot $B(C \to eX)$ vs $E_{c.m.}$ along with our value of the semileptonic branching ratio for the decay of the charmed D meson into an electron plus additional particles, $B(D \to eX) = (7.2 \pm 2.8)\%$, measured at the $\psi(3772)$.[6] An estimated 20% overall systematic error has not been included for the points in Fig. 3. We find $B(C \to eX)$ to be independent of $E_{c.m.}$, within errors, and
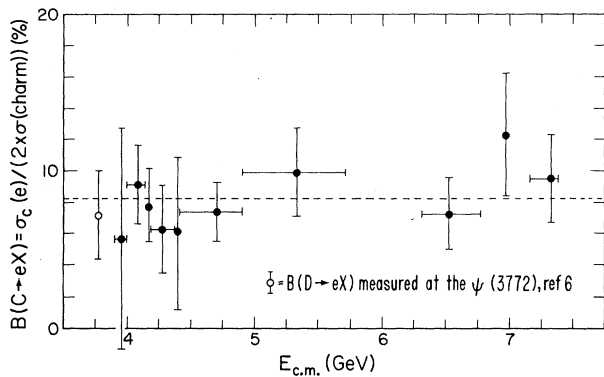
FIG. 3. The average branching ratio for charmed-particle decay into an electron plus additional particles, $B(C \to eX)$ vs the center-of-mass energy. The dashed line indicates the average value of this ratio for 3.9 $\leq E_{c.m.} < 7.4$ GeV.

obtain an average value for 3.9 $\leq E_{c.m.} < 7.4$ GeV of $(8.2 \pm 1.9)\%$, where we have included the 20% systematic error in quadrature.[15] This result is in agreement with the value of $(11 \pm 3)\%$ found at DORIS for the $E_{c.m.}$ range 3.9–5.2 GeV.[4]

In conclusion, we have observed inclusive electron production in multiprong events produced by e^+e^- annihilation over the $E_{c.m.}$ range 3.9–7.4 GeV. We find the electron signal to be consistent with coming mainly from charmed-particle production and semileptonic decay with about a 25% contribution from τ production and leptonic decay. We calculate an average charmed-particle branching ratio into an electron plus additional particles, $B(C \to eX) = (8.2 \pm 1.9)\%$, which is consistent with the value of $B(D \to eX)$ measured at the $\psi(3772)$ in this experiment[6] and the DELCO experiment.[7] We conclude that the data from higher $E_{c.m.}$ does not require production of new particles with semileptonic decay branching ratios significantly different from the D.

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[15] If the value of the branching ratio of the τ into multiprongs is 15% [35%] instead of 25%, the calculated value of $B(C \to eX)$ changes to $(9.1 \pm 2.1)\%$ [$(17.4 \pm 1.7)\%$].