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Prompt Electron Production in e^+e^- Annihilation at 29 GeV*

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ABSTRACT

We have studied the production of prompt electrons in a high statistics sample (118 pb^{-1}) of hadronic events from e^+e^- annihilation at 29 GeV. We measure the inclusive electron cross section, $\sigma(e^+e^- \rightarrow e^\pm X) = (35.8 \pm 4.6)$ pb in the momentum range $0.5 < p < 5.5$ GeV/c. The data are well fitted by a combination of bottom and charm quark decays with semielectronic branching ratios of $(14.6 \pm 2.8)\%$ and $(9.1 \pm 1.3)\%$, respectively. We observe no evidence of electron production from new sources and determine a cross section upper limit of 14 pb (95% CL) for this process. We find that the fragmentation functions are hard for both b and c, characterized by the mean values $< z_b > = 0.78 \pm 0.05$ and $< z_c > = 0.69 \pm 0.06$.

Prompt electrons provide an excellent tool to study the properties of heavy quarks and to identify new phenomena in e^+e^- annihilation into hadrons. At present energies there are two main sources of prompt electrons in hadronic events: b and c semileptonic decays. Electrons from these processes can be statistically distinguished by means of their characteristic distributions in p and p_t (relative to the event thrust axis) which reflect the different parent quark masses. In addition, the longitudinal momentum spectra are influenced by the quark fragmentation functions which parameterize the momentum distributions of the hadrons containing those quarks.

In this experiment we study prompt electron production over a broad kinematic range, $0.5 < p < 5.5$ GeV/c, in data recorded by the DELCO detector at PEP. The modifications to the original SPEAR detector have been described previously.[1] The particle momenta are measured without vertex constraint to a precision, $\sigma_p/p = \sqrt{[.02p(GeV/c)]^2 + 0.06^2}$, in an open-geometry magnet equipped with drift chambers. Electron identification is made primarily with a threshold Čerenkov counter although extra rejection of background particles is provided by a system of shower counters. The combined solid angle for electron identification is $0.52 \times 4\pi$ steradians.

Two separate experiments were carried out by filling the Čerenkov counter initially with isobutane and then with nitrogen gas. (In order to simplify the following discussion, we provide isobutane numbers followed by equivalent nitrogen numbers in parentheses.) The data correspond to an integrated luminosity of 92(26) pb^{-1} and $33.10^3(9.5\ \ .10^3)$ detected hadronic events. The primary criteria for selection of hadronic events are at least 5 charged particles emerging from the interaction region with a total (charged) energy above 6 GeV. An electron candidate is a track below the pion Čerenkov threshold of 2.5 (5.5) GeV/c, which triggers a Čerenkov cell. In cases where more than one track enter the same Čerenkov cell, each particle is required to be below pion threshold. Approximately 25% of the electrons share a Čerenkov cell with another track and these are treated by analysis of the Čerenkov and shower counter pulse heights. In addition, a low momentum cut of 0.5 GeV/c is made to avoid the loss of Čerenkov light due to track curvature. A positive Čerenkov response is required for each electron candidate, corresponding to a signal occurring within 3σ [1.0(1.5)ns] of the nominal time and with a pulse height above -1.5σ in the isobutane data or above 1.8 photoelectrons in the nitrogen data. The mean pulse height for $\beta = 1$ particles is 18 (4.6) photoelectrons. The lower cut on shower counter pulse height is 1.5σ below the response expected for an electron with the measured momentum; no upper cut is made due to the large probability of overlap with extra particles in the shower counter.

The background in the resulting electron sample is caused predominantly by γ-conversions and Dalitz decays. It has two components:

a) The electron candidate comes from a Dalitz decay or γ-conversion occurring near the entrance of the central tracking chambers (e.g. in the vacuum chamber). Most of these background events are removed by identifying an e^+e^- pair. Further suppression is obtained by requiring the candidate to project in the transverse plane within 3 mm of the interaction point and to register a hit in the innermost drift chamber. A subsequent visual scan removes most of the asymmetric pairs where one of the electrons has a very low momentum ($\sim$ 10-40 MeV/c) and is not found by the tracking program. The residual background is calculated by Monte Carlo[2] and subtracted statistically. We have verified this calculation by comparing the distributions of fully reconstructed e^+e^- pairs in the Monte Carlo and data.

b) The candidate is a hadron track traversing a Čerenkov cell which has been triggered by a γ-conversion occurring near or beyond the exit of the central tracking chambers. Approximately 75% of these late conversions are tagged and rejected because tracks reconstructed in the outer drift chambers (at the Čerenkov exit) are not matched with tracks in the central tracking chambers. The residual background is determined directly from the data and subtracted statistically. The technique involves taking each track in a hadronic event, reflecting it into the opposite jet, and then processing the event through the full electron selection analysis. In this way we measure the accidental association of tracks with Čerenkov and shower counters. The validity of this approach has been cross-checked by Monte Carlo calculation.

After these selection criteria are applied, but prior to the residual background subtraction, there remain 515(199) electron candidates. Fig. 1 shows the momentum distributions together with the individual backgrounds, which contribute 26 (18)% of the candidates. These backgrounds are subtracted, and the remaining data are corrected by a detection efficiency, which is determined by Monte Carlo calculation. The efficiency depends on p and p_t; it averages 53% for electrons inside the fiducial volume and within the momentum acceptance. Finally, after we normalize to the luminosity, the isobutane and nitrogen data are in excellent agreement. We show the momentum distributions in Fig. 2a after correcting for initial state radiation[3] and accounting for systematic errors, which are primarily due to uncertainties in detection efficiencies (9 %), luminosity (5 %) and background subtractions (4 %). The combined data are shown in Fig. 2b. Upon integrating this spectrum, we measure the prompt electron cross section, $\sigma(e^+e^- \rightarrow e^{\pm}X) = (35.8 \pm 4.6)$ pb, in the momentum range $0.5 < p < 5.5$ GeV/c at $E_{cm} = 29$ GeV.

We analyze the data in terms of the following signal contributions: primary ($b \rightarrow c\ e^- \bar{\nu}_e$) and secondary ($b \rightarrow c \rightarrow s\ e^+\nu_e$) decays in $b\bar{b}$ events, and primary ($c \rightarrow s\ e^+\nu_e$) decays in $c\bar{c}$ events. The number of $b\bar{b}$ and $c\bar{c}$ events are calculated from the total observed events, assuming production in proportion to the square of the quark charges. In calculating the secondary c flux, we assume[4] br($b \rightarrow c\ W^-_{virtual}$) = 100% and br($W^-_{virtual} \rightarrow \bar{c}\ s$) = 16%. We calculate and subtract the small contribution due to $\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$, assuming[4] the relative rate of $b \rightarrow c\ \tau^- \bar{\nu}_\tau$ to $b \rightarrow c\ e^- \bar{\nu}_e$

is 0.26. We have investigated two forms of the heavy quark fragmentation function, D(z): Peterson et al.[5] $[1/z\ \{1 - 1/z - \alpha\ /(1-z)\}^2\ ]$ and Field-Feynman[6] $[1 - \alpha + 3\alpha(1-z)^2]$, where the α are shape parameters to be determined by experiment. We define $z = 2\ E_H/\sqrt{s}$, where E_H is the energy of the hadron containing the heavy quark and $\sqrt{s}$ is the energy of the virtual photon produced in the e^+e^- collision after accounting for initial state radiation.

We perform a maximum likelihood fit to the total data (including background) in the p, p_t plane with the semielectronic branching ratios and the fragmentation shapes, α_b and α_c, left as free parameters. We account for systematic errors by including additional variable factors in the likelihood function. The results, summarized in Table 1, indicate that the branching ratio measurements are insensitive to the actual form of the fragmentation function. We determine the following semielectronic branching ratios: $\mathrm{br}_b = \mathrm{br}(b \rightarrow c\ e^- \bar{\nu}_e) = (14.6 \pm 2.8)\%$ and $\mathrm{br}_c = \mathrm{br}(c \rightarrow s\ e^+ \nu_e) = (9.1 \pm 1.3)\%$. We have studied the sensitivity of these measurements to the low momentum region, where the backgrounds are largest, by excluding from the fit electrons below 1 $\sim$ 2 GeV/c, and we find results which are consistent with those in Table 1. However, if the low momentum electrons are excluded, we find strong correlations between the branching ratios and the fragmentation functions. The results of the fit (using the fragmentation function of ref. 5) are shown with the momentum distribution in Fig. 2b and with the transverse momentum distribution in Fig. 3.

Our measurements are consistent with previous values obtained at PEP and PETRA for the semielectronic[7] and semimuonic[8] branching ratios. The previous experiments, however, were insensitive to leptons below approximately 2 GeV/c where most of the spectrum is contained. With our broad momentum coverage it is possible to search for new processes by comparing our measurements with those obtained in the $b\bar{b}$ and $c\bar{c}$ resonance regions. The low energy measurements are: $\mathrm{br}_b = (11.6 \pm$

0.6)%[9] and br_c = (8.0 ± 1.1)%[10]. These values are in agreement with ours and we conclude that these data show no evidence of a new threshold in anomalous electron production. After subtracting the b and c contributions inferred from the low energy experiments, we measure a cross section upper limit of 14 pb (95% CL) for electron production from new sources.[11]

Our data are well fitted by both forms of the fragmentation function with the parameters indicated in Table 1. Although we are unable to measure the detailed shapes of the fragmentation functions, we establish a hard spectrum for both b and c with the mean values, $<z_b> = 0.78 \pm 0.05$ and $<z_c> = 0.69 \pm 0.06$.[12] These observations are consistent with earlier measurements of b fragmentation in electron[7] and muon[8] experiments. They are also consistent with previous measurements of c fragmentation in e^+e^- annihilation, which have involved a direct fit to the observed D^* spectrum[13]. In order to compare the latter measurements with our data, we redefine $z = E_H/E_{BEAM} = E_H/14.5$ for which the corresponding values in the Peterson et al. fit are $\alpha_c = 0.071^{+.076}_{-.038}$ and $<z_c> = 0.66 \pm 0.06$, also $\alpha_b = 0.025^{+.034}_{-.015}$ and $<z_b> = 0.76 \pm 0.06$. On comparing these values with Table 1, we see the effect of initial state radiation is to reduce $< z >$ by approximately 2-4%.

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Table 1. Results of the Fits to the p, p_t

Distribution of Electrons

(Systematic errors are included)

Fragmentation Function	Peterson et al.[5]		Field-Feynman[6]	
Quark	b	c	b	c
Semielectronic br.%	14.8 ± 2.8	9.0 ± 1.3	14.4 ± 2.6	9.2 ± 1.3
Fragmentation Parameter, α	$.018^{+.024}_{-.011}$	$.050^{+.060}_{-.030}$	$-5.0^{+3.6}_{-15.0}$	$-1.5^{+0.6}_{-1.8}$
$< z >$	$.78 \pm .05$	$.69 \pm .06$	$.78 \pm .04$	$.75 \pm .04$
χ^2/dof	65/57		65/57	

References

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11. This limit takes into account possible differences between our experiment and those at low energy in the composition of the heavy quark hadrons.

12. These values are derived from the fragmentation function of ref. 5 since the form of ref. 6 is saturated.

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Figure Captions

1. The momentum spectrum of the electron candidates (solid line), together with the calculated residual backgrounds due to electrons from Dalitz pairs and γ conversions (dashed line) and due to hadrons (dotted line).

   a) Isobutane data (515 events): The backgrounds comprise 8% and 18% , respectively, of the total candidates.

   b) Nitrogen data (199 events): The corresponding background fractions are 7% and 11% , respectively.

2. a) The differential cross section distribution, $d\sigma/dp$, of prompt electrons measured in the isobutane (circles) and nitrogen data (squares). The MarkII measurement[7] is indicated by the triangles. The vertical bars account for statistical and systematic errors.

   b) The differential cross section distribution, $d\sigma/dp$, for the combined isobutane and nitrogen data. The solid curve shows the fit using the fragmentation function of ref. 5. The individual contributions from b primary (dash-dotted), b secondary (dotted) and c (dashed) are also indicated.

3. The prompt electron differential cross section distribution, $d\sigma/dp_t$, measured in the nitrogen data. The transverse momentum, p_t, is evaluated with respect to the event thrust axis. The curves correspond to those in Fig. 2b.

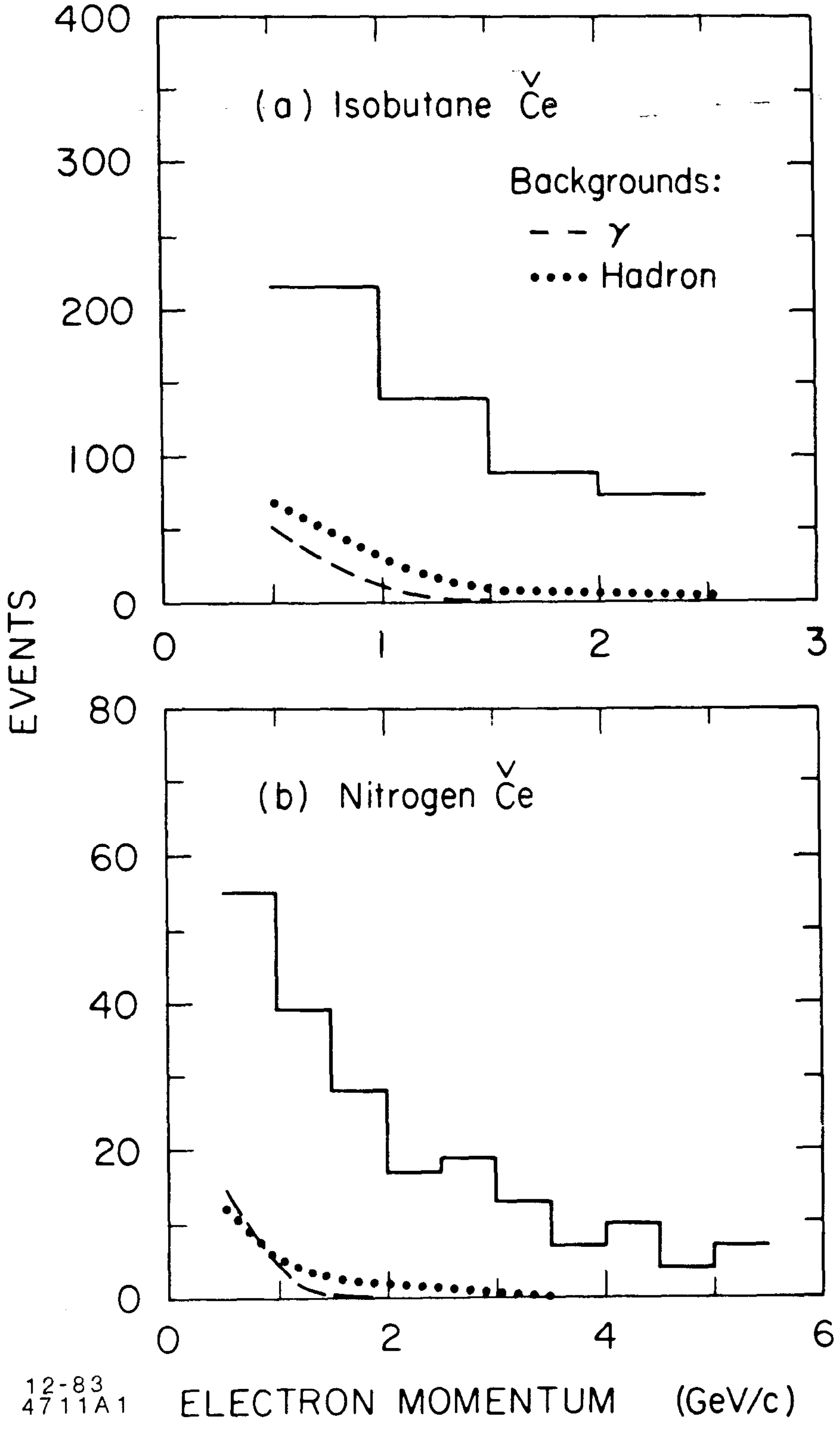
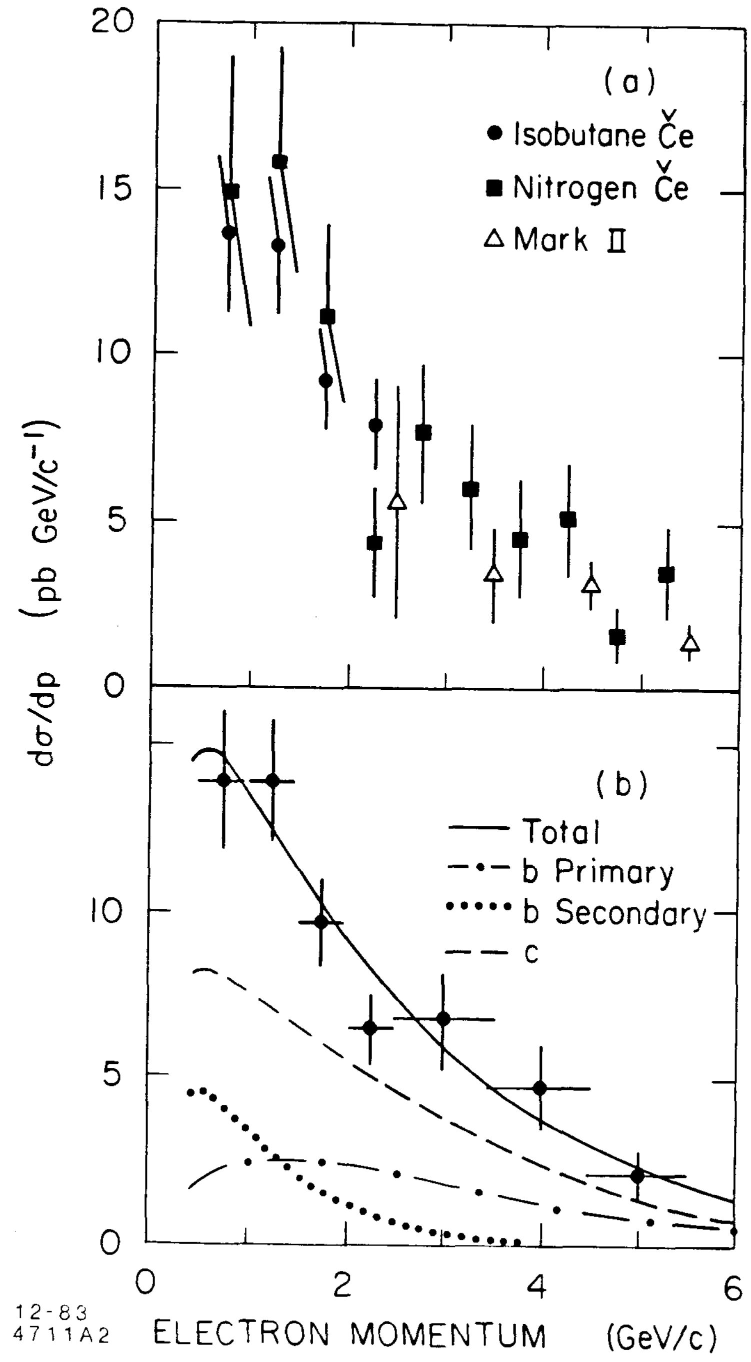

(a) Isobutane Če
Backgrounds:
γ
Hadron
400
300
200
100
0
0
1
2
3
EVENTS
80
(b) Nitrogen Če
60
40
20
0
0
2
4
6
12-83
4711A1
ELECTRON MOMENTUM (GeV/c)

Fig. 1



(a)
Isobutane Če
Nitrogen Če
Mark II
(b)
Total
b Primary
b Secondary
c
dσ/dp (pb GeV/c⁻¹)
ELECTRON MOMENTUM (GeV/c)
12-83
4711A2

Fig. 2

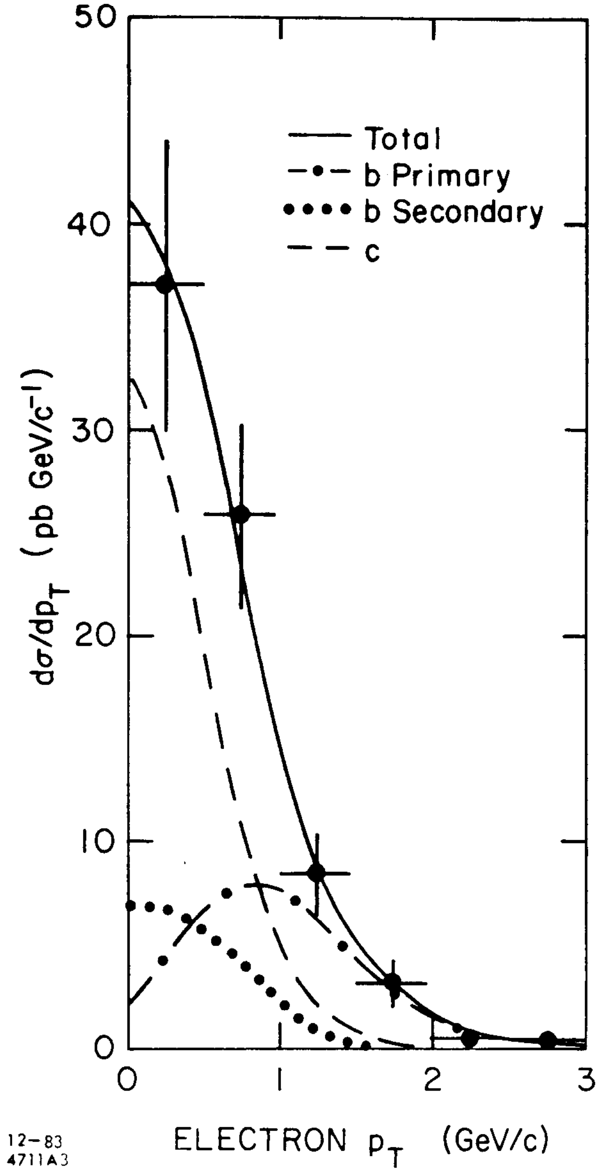

Total
b Primary
b Secondary
c
dσ/dp_T (pb GeV/c^-1)
ELECTRON p_T (GeV/c)
50
40
30
20
10
0
0
1
2
3
12–83
4711A3

Fig. 3