Evidence for New-Flavor Production at the Υ(4S)

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An enhancement has been observed in the inclusive cross section for direct single electrons produced in e^+e^- annihilations at the Υ(4S). This is interpreted as evidence for a new weakly decaying particle, the B meson. A branching ratio for $B \to Xe\nu$ of $[13 \pm 3 (\pm 3)]\%$ is inferred, where the first set of errors is statistical and the estimated systematic error is enclosed in parentheses.

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The recently discovered resonance in e^+e^- annihilations at 10.55 GeV total energy[1,2] has a natural interpretation as the Υ(4S) bound state of $b\bar{b}$ quarks. Its width indicates that this state is above the threshold for producing pairs of B mesons, bound states of b quarks with $\bar{u}$ or $\bar{d}$ quarks, and has as its dominant decay mode $B\bar{B}$ meson final states.[3] The existence of a new, weakly decaying flavor can be inferred from the semileptonic decay $B \to Xl\nu$ and the branching ratio (BR) for this

decay can be determined by studying the yield of
directly produced single leptons in the $\Upsilon(4S)$ en-
ergy region. In this Letter, we present cross
sections for electron production and a branching
ratio for the decay $B \to Xe\nu$. Similar results for
muons are reported by Chadwick et al.[4]

The CLEO detector at the Cornell electron
storage ring was used to identify events which
contained a directly produced single high-momen-
tum (≥ 1 GeV/c) electron or positron. Charged-
particle momenta were measured with use of a
1-m-radius solenoid magnet containing cylindri-
cal tracking chambers. External to the magnet
coil are Cherenkov counters and shower counters
which were used for identifying electrons. The
detector is described in further detail by Krei-
nick.[5]

In a sample of hadronic events selected as de-
scribed in Ref. 1, a charged particle with mo-
mentum above 1 GeV/c which fired a Cherenkov
counter was called an electron (or positron) if its
shower energy, E_s, was greater than half its
measured momentum p, if at least 10% of the
shower energy was deposited in the first 3.3 radi-
ation lengths of the shower counter, if the posi-
tion of the associated shower agreed with the po-
sition of the projected track from the inner cham-
bers to within ± 20 cm, and if the width of the
shower was consistent with that expected for elec-
trons. Tracks were rejected if there was an op-
positely charged track in the event which had a
0° opening angle with the candidate track, as
would be expected from γ conversion. In order
to suppress electron events which originated
from Bhabha scattering, τ decays and two-photon
processes, events were required to have an ob-
served charged multiplicity of 5 or greater.

The shower detectors consist of 44 layers of
gas proportional tubes interspersed with 0.27–
radiation-length–thick lead sheets. The tubes
are ganged into cells with lateral dimensions
which range from 3.2 cm near the front to 12.5
cm at the back of the detector. Pulse heights
from each hit cell were digitized and read out for
each event. The solid histogram in Fig. 1(a) is
the average number of hit cells per hit layer in
the shower detector for the electron candidates.
This distribution, which peaks at 2.3, should be
compared to the dashed histogram which shows
the same quantity plotted for tracks with momen-
ta between 1.0 and 3.0 GeV/c that were unambig-
uously determined to be either pions or kaons by
means of dE/dx measurements.[6] Shown in Fig.
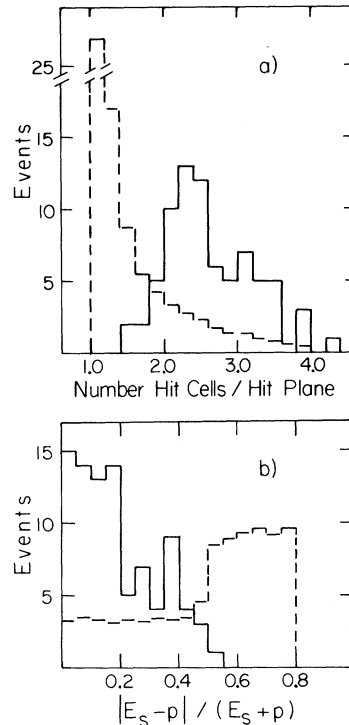1(b) are distributions in $|E_s - p|/(E_s + p)$ for the

FIG. 1. (a) The average number of hit cells per hit
plane in the shower counter for electron candidates
(solid lines) and identified pions/kaons (dashed lines)
normalized to the same area. To qualify as electron
events, electron candidates must lie above 1.5 on the
abscissa. (b) $|E_s - p|/(E_s + p)$ for electron candidates
(solid lines) and identified pions/kaons (dashed lines)
normalized to the same area. Electron candidates are
required to have $|E_s - p|/(E_s + p)$ less than 0.33 to
qualify as electron events.

electron candidates (solid line) and the pion/kaon
tracks (dashed line). Electron events are re-
quired to have the average number of hit cells per
hit plane greater than 1.5 and to have $|E_s - p|/$
$(E_s + p)$ less than 0.33. The distributions in both
variables show marked differences between the
electron candidates and the pion/kaon sample in-
dicating the effectiveness of the electron selec-
tion criteria.

We summarize the results of the electron event
selection in Table I. The number of electron
events along with the associated integrated lumi-
nosity are indicated for each of seven energy
bins. The corresponding visible cross sections
are plotted in Fig. 2(b), where an enhancement is
apparent at the energy of the $\Upsilon(4S)$. About one-
third of the cross section in the continuum is due
to electrons from D decays. The remaining off-
resonance cross section is consistent with the ex-

TABLE I. Summary of electron events.

Beam energy (GeV)	L (nb^{-1})	Number of events	σ_e^{vis} (pb)
5.189–5.224	352.0	4	11.4 ± 5.7
5.224–5.264	488.1	6	12.3 ± 5.0
5.264–5.269	130.6	5	38.3 ± 17.1
5.269–5.274	527.0	30	56.9 ± 10.4
5.274–5.279	499.4	22	44.1 ± 9.4
5.279–5.284	268.3	4	14.9 ± 7.5
5.284–5.299	217.4	5	23.0 ± 10.3

pected levels of hadronically induced backgrounds, i.e., fake electron signals from charge exchange in the coil and from random overlapping of charged-particle tracks and γ rays which convert in the 1–radiation-length–thick aluminum coil. The data in the bins corresponding to the peak can be combined to give an enhancement in the visible cross section of 28.6 ± 6.6 pb.

Two sources of electrons are expected from the $\Upsilon(4S)$; those from the semileptonic decay $B \to Xe\nu$ and those from the semileptonic decays of charmed particles which are expected to be daughter products of B decays.[7] In most theoretical pictures where the quark transition $b \to c$ dominates, between 70% and 80% of the direct-
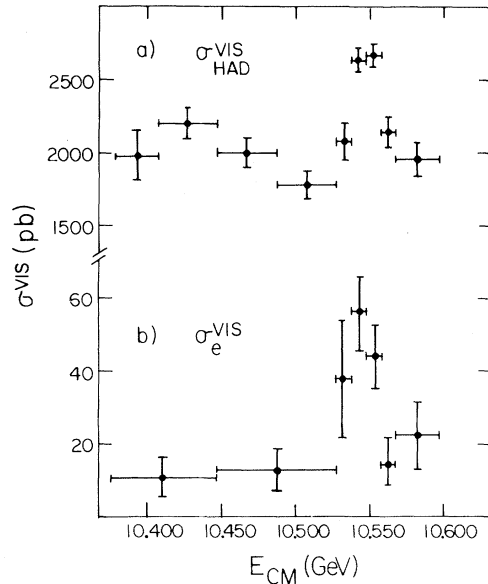

FIG. 2. The visible cross section for the production of (a) hadronic events of multiplicity five or greater (note suppressed zero) and (b) electrons above 1 GeV/c. These cross sections have not been corrected for acceptance or efficiency.

electron-momentum spectrum lies about 1 GeV/c. The electron-momentum spectrum from the semileptonic decays of daughter D mesons can be estimated and we find less than 10% of the electrons have momenta above 1 GeV/c. Shown in Fig. 3 is the momentum distribution of the electron candidates for those events which correspond to the peak in Fig. 2(b). Also shown in Fig. 3 is an estimate of the expected electron-momentum spectrum. An equal mixture of $B \to De\nu$ and $B \to D^*(2000)e\nu$ decays is assumed and secondary decays $D \to Xe\nu$ are also included. For this estimate a phase space distribution was used for the final-state particles and the electron momentum was smeared to simulate the effect of the detector momentum resolution. The data show a shape which is quite similar to the computed curve and we interpret these events as originating primarily from semileptonic decays of B mesons.

If we assume that the $\Upsilon(4S)$ decays exclusively into $B\bar{B}$, as is indicated by its width, we can infer a branching ratio R for $B \to Xe\nu$ via the relation

$$R = (\Delta\sigma_e^{vis}/\epsilon_{Ch}\epsilon_A)[2(\Delta\sigma_{had}^{vis})f]^{-1},$$

where the terms are defined as follows: $\Delta\sigma_e^{vis}$ = 26.8 ± 6.6 pb is the enhancement in the visible-electron cross section[8] at the $\Upsilon(4S)$; ϵ_{Ch} = 0.31 ± 0.05 is the product of the geometrical acceptance and efficiency of the Cherenkov counters, determined from Bhabha scattering and μ-pair events; ϵ_A = 0.78 ± 0.10 is the efficiency of the electron identification algorithm which was estimated from the data[9]; $\Delta\sigma_{had}^{vis}$ = 0.52 ± 0.06 nb is
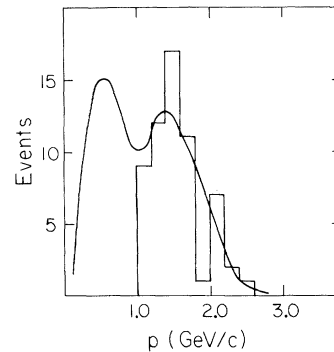

FIG. 3. The histogram is the raw momentum spectrum of the electrons from the $\Upsilon(4S)$ peak. The curve is a Monte Carlo estimate of the combined electron spectrum expected from $B \to De\nu$, $B \to D^*(2000)e\nu$, and $D \to Xe\nu$ decays. The peak at ~1.4 GeV/c is due to B decays; the one at ~0.5 GeV/c to daughter D decays. No events appear below 1 GeV/c due to our cut at that momentum.

the enhancement, shown in Fig. 2(a), in the visible hadronic cross section at the $\Upsilon(4S)$ in data subject to the same binning used to obtain $\Delta\sigma_e^{\text{vis}}$; $f = 0.75 \pm 0.05$ is the fraction of electrons from $B \to Xe\nu$ estimated to have a momentum above 1 GeV/c.

Finally, the result has been reduced by 1 percentage point to account for electrons originating from semileptonic decays of D meson products of B decays.[10] The resulting branching ratio,[11] averaged over B states, is

$$R(B \to Xe\nu) = [13 \pm 3 \ (\pm 3)]\%,$$

where the first set of errors is statistical and the estimated systematic error is enclosed in parentheses.

The total electron sample included one two-electron event at an energy slightly above the $\Upsilon(4S)$ resonance which was consistent with the decay of a ψ. At the $\Upsilon(4S)$ resonance, no two-electron events were seen, providing an upper limit for the branching ratio for $B \to Xee$ of 5% (at 90% confidence level).

In summary, we have observed a clear enhancement in the production of energetic electrons at the $\Upsilon(4S)$ resonance. The momentum distribution of these electrons is consistent with what is expected from the weak decay of new flavor in which the quark transition $b \to c$ dominates. We interpret these results as evidence for the existence of b-flavored mesons and have inferred a semileptonic branching ratio for this particle.

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[1]D. Andrews et al., Phys. Rev. Lett. 45, 219 (1980).

[2]G. Finocchiaro et al., Phys. Rev. Lett. 45, 223 (1980).

[3]A higher-mass B^* may also be produced at the $\Upsilon(4S)$. If we assume that $B^* \to B + \gamma$, our conclusions about B decays will not be affected.

[4]K. Chadwick et al., following Letter [Phys. Rev. Lett. 46, 88 (1981)].

[5]David L. Kreinick, Cornell Laboratory for Nuclear Studies Report No. 80/460, 1980 (unpublished).

[6]For details on the dE/dx system, see R. Ehrlich et al., Cornell Laboratory for Nuclear Studies Report No. 80/459, 1980 (to be published).

[7]M. Kobayashi and K. Maskawa, Prog. Theor. Phys. 49, 652 (1973).

[8]$\Delta\sigma_e^{\text{vis}}$ has been reduced by 6% to correct for hadronic events mistakenly identified as electronic events.

[9]This includes the effects of (i) shower-counter–track-chamber matching, 0.88 ± 0.07; (ii) shower-counter resolution effect, 0.93 ± 0.07; (iii) event complexity (overlapping tracks, etc.), 0.95 ± 0.05.

[10]We use a branching ratio R for $B \to DX$ of 100% coupled with a 10% average D semileptonic branching ratio and a 10% relative detection efficiency for electrons from D's compared to those from B's to estimate the contamination from D's. The effect of electrons from decays of τ's coming from $B \to X\tau\nu$ is estimated to be negligible.

[11]A second estimate of the branching ratio for $B \to Xe\nu$ was made using dE/dx chambers in conjunction with the shower chambers to identify electrons (two octants of the CLEO detector contain dE/dx chambers, the remaining six contain Cherenkov counters). We observe an increase in the electron signal at the $\Upsilon(4S)$. The branching ratio measured is $[23 \pm 10 \ (\pm 6)]\%$.