Charged-Particle Multiplicities in *B*-Meson Decay

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The charged multiplicity has been measured at the $\Upsilon(4S)$ and a value of $5.75 \pm 0.1 \pm 0.2$ has been obtained for the mean charged multiplicity in B-meson decay. Combining this result with the measurement of prompt leptons from B decay, the values $4.1 \pm 0.35 \pm 0.2$ and $6.3 \pm 0.2 \pm 0.2$ are found for the semileptonic and nonleptonic charged multiplicities, respectively. If $b \to c$ dominance is assumed for the weak decay of the B meson, then the semileptonic multiplicity is consistent with the recoil mass determined from the lepton momentum spectrum.

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Evidence collected to date[1-3] convincingly shows that the $\Upsilon(4S)$ resonance decays strongly into mesons containing a b quark which subsequently undergo weak decay. We report here a measurement of the charged-particle multiplicity on and off the $\Upsilon(4S)$ resonance and relate this to the properties of the B meson.

The data were collected using the magnetic detector CLEO[1] at the Cornell Electron Storage Ring. A cylindrical proportional wire chamber and drift chamber comprise the charged-track detector which lies inside a 1-m-radius aluminum solenoid operated at 4.2 kG. Particle identification is provided outside the coil by a system of eight octants containing planar drift chambers, time-of-flight counters, proportional tube shower counters, Cherenkov counters, and specific ionization (dE/dX) detectors. Surrounding the entire assembly is an iron hadron filter followed by drift chambers for muon detection. The hadron event trigger required three charged tracks in coincidence with two time-of-flight counters located in separate octants.

The data sample included in this study was obtained from 5502 nb^{-1} of luminosity accumulated on the $\Upsilon(4S)$ resonance ($10.538 < W < 10.558$ GeV) and 3204 nb^{-1} taken below ($10.378 < W < 10.528$ GeV). In order to be included in the hadronic sample, an event had to meet the following criteria: (1) have a primary vertex consistent with the beam crossing point; (2) possess five or more charged tracks pointing to the primary vertex (these include tracks coming from K^0 or Λ decays); (3) have at least 30% of the center-of-mass energy appear as charged tracks; and (4) not be consistent with a beam-wall interaction. The numbers of events satsfying these requirements are 16 562 on resonance and 6684 off resonance, yielding a direct $\Upsilon(4S)$ sample of 5082 ± 190 events. Visual scanning verified that the resulting data sample suffered negligible contamination from beam-gas, beam-wall, two-photon, $\tau^+\tau^-$, or radiative Bhabha processes.

We assume in the following discussion that the $\Upsilon(4S)$ decays 100% of the time into B mesons; hence quantities obtained by subtraction of the continuum from the resonance are labeled "$B\overline{B}$." We are unable to differentiate between the charged and neutral B.

Figure 1 shows the observed $B\overline{B}$ and continuum charged multiplicity distributions normalized to the $B\overline{B}$ sample size. To be included in the plot a track was required to come from the primary vertex or else be a secondary resulting from K^0 or Λ decay. Observed gamma conversions in the beam pipe were rejected although our efficiency for detecting such conversions is only 30%. The disparity between the two distributions is reflected in the mean values: 8.00 ± 0.03 for the continuum and 9.69 ± 0.10 for the $B\overline{B}$.

The observed charged multiplicity distribution must be corrected for detector acceptance. In order to accomplish this we simulated the continuum and $B\overline{B}$ processes using a Monte Carlo procedure similar to one developed by Sjostrand.[4] The continuum model assumes that a primary $q\overline{q}$ pair hadronizes into two jets following the Field-Feynman[5] prescription with the exception that four-momentum is conserved at every step and gluons are emitted (and allowed to hadronize) according to QCD.

Because the B^+ and B^0 masses are not known,

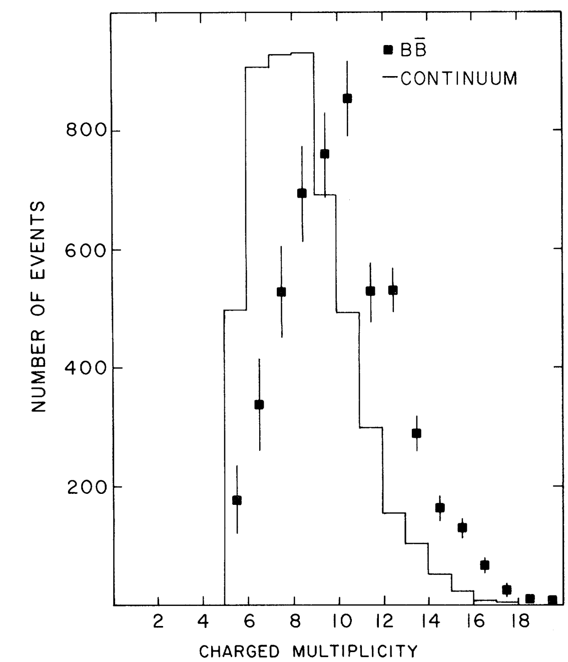

FIG. 1. Observed charged multiplicity distributions for continuum and $B\overline{B}$ data (continuum subtracted). The continuum data have been normalized to the $B\overline{B}$ sample size.

the model treats $B\overline{B}$ production as an equal mixture of B^+B^- and $B^0\overline{B}^0$. B decay is simulated by a spectator process in which the b quark decays weakly (assuming 100% $b \to c$) into quark and lepton final states according to branching fractions obtained by combining our semileptonic data[2] with theoretical predictions[6] of the relative hadronic rates. Pairs of light quarks are then created from the sea and allowed to combine with the primary quarks to produce mesons into which the B decays by phase space. The results reported here are insensitive to details of the production mechanism, including substituting $b \to u$ for $b \to c$ dominance.

The effect of the Monte Carlo simulation can be expressed in the form of a probability matrix P relating the observed number of charged particles to the number actually generated, e.g.,

$$O_m = \sum_n P_{mn} G_n ,$$

where O_m denotes the number of events containing m observed charged tracks and G_n is the number of events with n generated charged tracks. The values of the matrix P_{mn} are determined from the Monte Carlo calculation, which includes such detector-related effects as acceptance and resolution as well as processes that change particle number, namely decay in flight and photon conversions in the beam pipe.

Using the matrix method we can determine the range of possible charged multiplicity distributions that are consistent with the observed data in Fig. 1. We obtain $5.75 \pm 0.1 \pm 0.2$ for the mean charged multiplicity in B decay, where a systematic error has been added to reflect the uncertainty in the detector simulation. For the continuum we find a mean of $8.1 \pm 0.1 \pm 0.3$ which is consistent with previous measurements[7] at nearby center-of-mass energies.

It has been experimentally found[8] that the multiplicity distributions of a wide variety of processes can be expressed as $f(n/\langle n\rangle)$, where $\langle n\rangle$ is the mean multiplicity and f is a function that depends only on the type of reaction being considered. In particular, the ratio $D/\langle n\rangle$, where $D = (\langle n^2\rangle - \langle n\rangle^2)^{1/2}$ (the dispersion), is independent of energy. The matrix technique yields for $D/\langle n\rangle$ a value of 0.40 ± 0.03 for B decay and 0.34 ± 0.03 for continuum production. The latter value agrees with measurements[7] made at center-of-mass energies ranging from 5 to 30 GeV.

The enhancement in electron and muon production observed previously at the $\Upsilon(4S)$,[2] in conjunction with the mean charged multiplicity derived above, can be used to determine the average semileptonic and nonleptonic charged multiplicities in B decay. The mean multiplicity can be expressed as a weighted sum of semileptonic and nonleptonic processes:

$$N_B = 2B_l N_s + (1 - 2B_l)N_h,$$

where N_B, N_s, and N_h are, in order, the average, semileptonic, and nonleptonic B charged multiplicities and $B_l = 0.12 \pm 0.02$ is the inclusive branching fraction of B mesons into electrons (or muons).[3] We are including in N_h a possible contribution due to semileptonic decays involving taus.

The multiplicity distributions for $B\bar{B}$ events containing electrons or muons (Fig. 2) were obtained using lepton selection criteria described in previous reports,[2,3] and were corrected for hadron contamination and secondary leptons resulting from decays of τ, D, and F particles. The means of these distributions are

$$N_{\text{lep}} = 8.30 \pm 0.27 \text{ for muons,}$$

$$N_{\text{lep}} = 8.39 \pm 0.30 \text{ for electrons.}$$

Combining these distributions and using the matrix procedure outlined above, we find

$$N_s = 4.1 \pm 0.35 \pm 0.2, \quad N_h = 6.3 \pm 0.2 \pm 0.2.$$

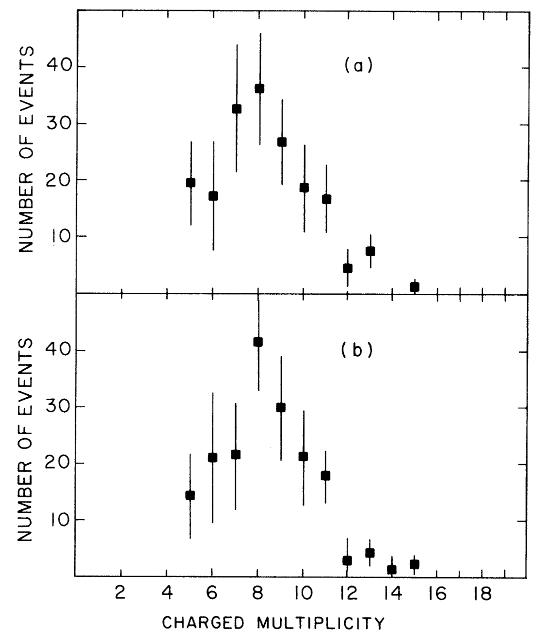

FIG. 2. Charged multiplicity distribution in $B\bar{B}$ events containing (a) muons and (b) electrons.

We can apply the preceding results to study the degree of hadronization present in B-meson decay under the assumption that b quarks always decay into final states containing a c quark. Such an assumption is supported by the large kaon multiplicity observed in B decay.[3] If, for example, the c quark fragments into an equal mixture of D and D^* mesons, then we can subtract the measured charged multiplicity of such a mixture[9] (2.5 ± 0.1) to obtain $0.55 \pm 0.35 \pm 0.2$ and $3.8 \pm 0.2 \pm 0.2$ as the number of charged hadrons produced in addition to charmed mesons in semileptonic and nonleptonic B decay, respectively. This small amount of fragmentation in the semileptonic decays is consistent with the recoil mass of approximately 2 GeV/c^2 determined from our lepton momentum spectra.[3]

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