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Charged Particle Multiplicity in B-Meson Decay

CLEO Collaboration

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Abstract

We have studied the charged particle multiplicity in B meson decays using the CLEO II detector at the Cornell Electron Storage Ring. Our measurement of the mean charge multiplicity in $B\bar{B}$ events at the $\Upsilon(4S)$ resonance is $10.76 \pm 0.015 \pm 0.28$ corresponding to a mean multiplicity of $5.38 \pm 0.008 \pm 0.14$ charged tracks per B meson decay.

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I. INTRODUCTION

There has been great progress in understanding weak decays of the B meson in recent years. However, we do not yet have a good theoretical description of inclusive properties in B decays due to the nonperturbative nature of QCD at low energy. Properties such as the charged particle multiplicity are measured empirically and then used to tune theoretical models.

Charged particle multiplicity in B meson decay indirectly affects all B physics analyses at CLEO through the overall reconstruction efficiency of events from the $\Upsilon(4S)$ resonance. For some analyses, which use sophisticated event shape cuts or neutrino reconstruction via total energy and missing momentum of the event, the uncertainty in charge multiplicity is a potential source of systematic bias. Other B physics studies at LEP and the Tevatron, *e.g.*, inclusive B tagging via secondary B vertex reconstruction, also rely on the CLEO measurement of the charged track multiplicity. The last CLEO measurement was performed in 1984 using approximately 50000 $B\bar{B}$ decays from the $\Upsilon(4S)$ [1]. We present here a new measurement using roughly 30 times more data.

II. EVENT AND TRACK SELECTION

The data sample used in this study was collected with the CLEO-II detector [2] at the Cornell Electron Storage Ring (CESR). It consists of 1.4 fb^{-1} integrated luminosity on the $\Upsilon(4S)$ resonance (1.5 million $B\bar{B}$ events) and 633 pb^{-1} at a center-of-mass energy 65 MeV below the resonance.

Charged particles are tracked with three concentric cylindrical wire chambers extending from 4 cm to 95 cm radially from the beam axis and operating in a 1.5 T magnetic field. The outer tracking chamber measures specific ionization (dE/dx) which is used for particle identification. The tracking chambers are followed by time-of-flight counters which provide additional particle identification information. Beyond these counters but still inside the superconducting magnet coil is an electromagnetic calorimeter consisting of 7800 CsI crystals covering 98% of the solid angle. Outside the coil is an iron yoke for field return with chambers interspersed for muon identification.

Hadronic events are selected by requiring a minimum of three charged tracks and the energy deposited in the calorimeter to be greater than 15% of the center-of-mass energy. Charged tracks are required to have z impact parameter less than 5 cm and $r - \phi$ impact parameter within 1 cm of the beam spot. Each track must have momentum greater than 50 MeV/c and lie inside the region $|cos\theta| < 0.9$, where θ is the polar angle.

In this analysis we assume that the $\Upsilon(4S)$ decays only to a pair of B mesons. The major source of background results from continuum processes, such as $e^+e^- \to q\bar{q}$ and $\tau^+\tau^-$, under the $\Upsilon(4S)$ resonance. The yield of events with a given multiplicity is measured in both the On-4S and Below-4S data samples. The yields from B meson decays are determined by subtracting the distribution obtained in the Below-4S sample, scaled for the relative luminosities between the On-4S and Below-4S data and corrected for $1/s$ scaling (about 1%) in the e^+e^- annihilation cross section, from the On-4S sample.

There are also other types of background events such as beam-gas and beam-wall events, which are left over after the continuum subtraction, due to changes in CESR beam conditions. These events are suppressed by requiring that each event must satisfy the following criteria:

$$4 \text{ GeV} < |E\_tot = \sum E_i| < 12 \text{ GeV}$$

$$|\vec{P}\_miss = \sum \vec{p_i}| < 3 \text{ GeV}/c.$$

We estimate how many of these events still pass through the cuts from the study of beam-gas events with the Z position of the event vertex displaced from the interaction point, and effectively subtract them (approximately 0.2% of the $B\bar{B}$ events).

III. MULTIPLICITY MEASUREMENT AND UNFOLDING

The charge multiplicity of each hadronic event, m, is determined by summing the number of charged tracks which pass the above track quality cuts. The reconstructed charge multiplicity distributions for the On-4S and scaled Below-4S data are shown in Figure 1(a). The charge multiplicity distribution after the continuum subtraction is shown in Figure 1(b). To unfold the actual multiplicity distribution from the observed multiplicity distribution in Figure 1(b), we apply a fitting method as described below.

Using $B\bar{B}$ Monte Carlo, we determine the actual charge multiplicity, n, and the observed multiplicity, m, for each Monte Carlo event. This allows us to construct an observed charge multiplicity histogram for each value of n. Thirteen histograms ($n = 2$ to 26) determined in this way are used as a basis set of functions in MINUIT [3], to fit the observed multiplicity distribution in Figure 1(b). Charged tracks produced in secondary vertices from long-lived particles such as K_S and Λ are included as long as they decay within the detector volume. The fit to the data is shown in Figure 2. The results of the fit after χ^2 minimization are shown in Figure 3. For each n, the fitted number of events, N_n, in the data is shown.

The mean charge multiplicity is calculated by averaging the number of events for each N_n weighted by n. The statistical error on the mean multiplicity is calculated using the full covariant error matrix returned from MINUIT since the 13 coefficients are highly correlated. The measured mean charge multiplicity in $B\bar{B}$ events is 10.76 ± 0.015, which is about 0.24 tracks lower than the previous CLEO measurement [1].

IV. SYSTEMATIC UNCERTAINTY

Even though the single track efficiency for CLEO II data is known to better than 1% [5], it is the largest source of systematic uncertainty in this analysis. The effect on the multiplicity measurement from changing the single track efficiency is difficult to determine in the CLEO Monte Carlo, which is a GEANT [4] simulation, because there is no simple mechanism to vary the tracking efficiency. Hence, we parameterize the reconstructed charge multiplicity distribution for each n-track multiplicity with the binomial distribution,

$$B_\varepsilon^n(m) = \binom{n}{m} \varepsilon^m (\varepsilon - 1)^{n-m}, \tag{1}$$

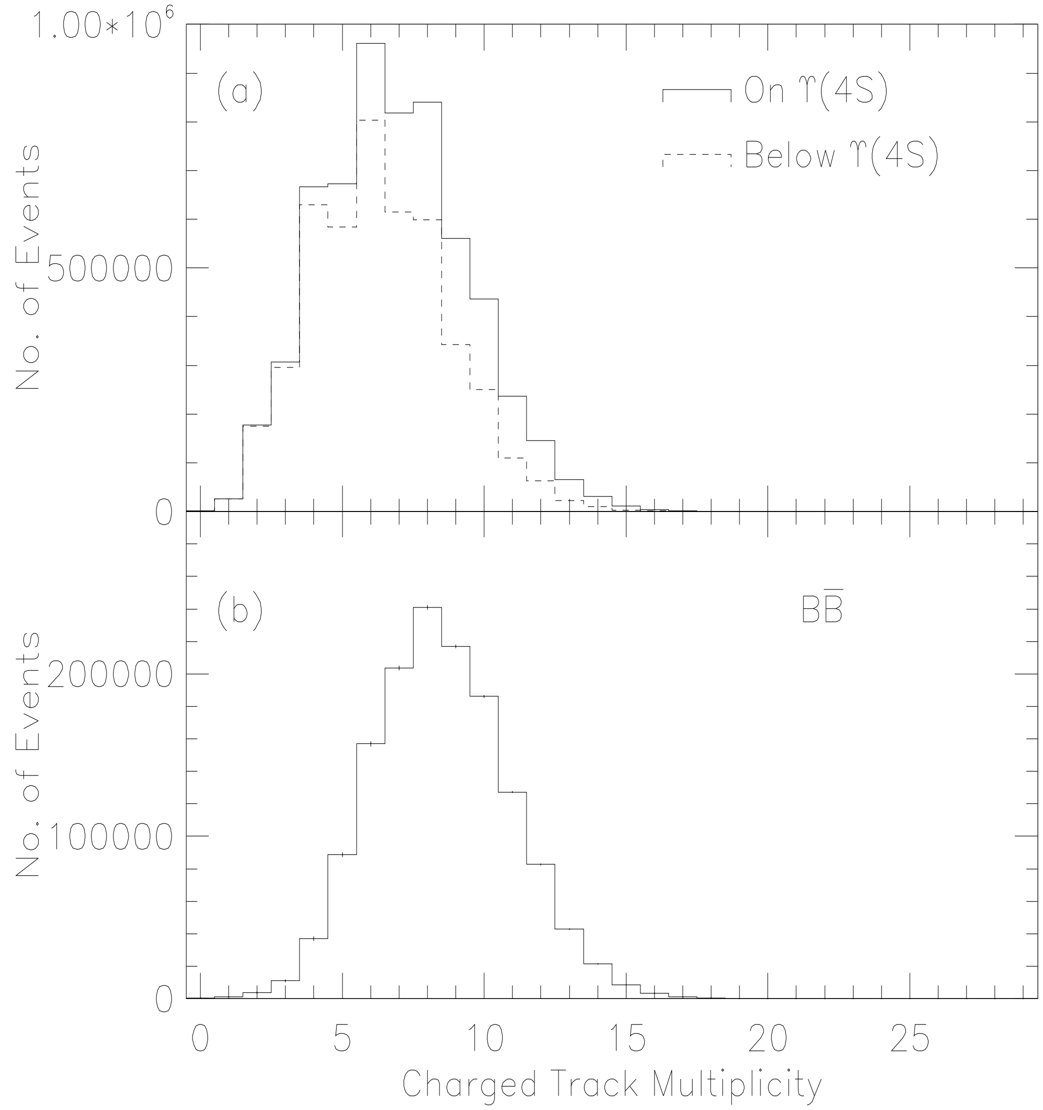

FIG. 1. (a) Reconstructed charge multiplicity distributions for the On-4S data (solid histogram) and the luminosity-scaled Below-4S data (dashed histogram); (b)Charge multiplicity distribution after the continuum subtraction. Error bars are plotted.

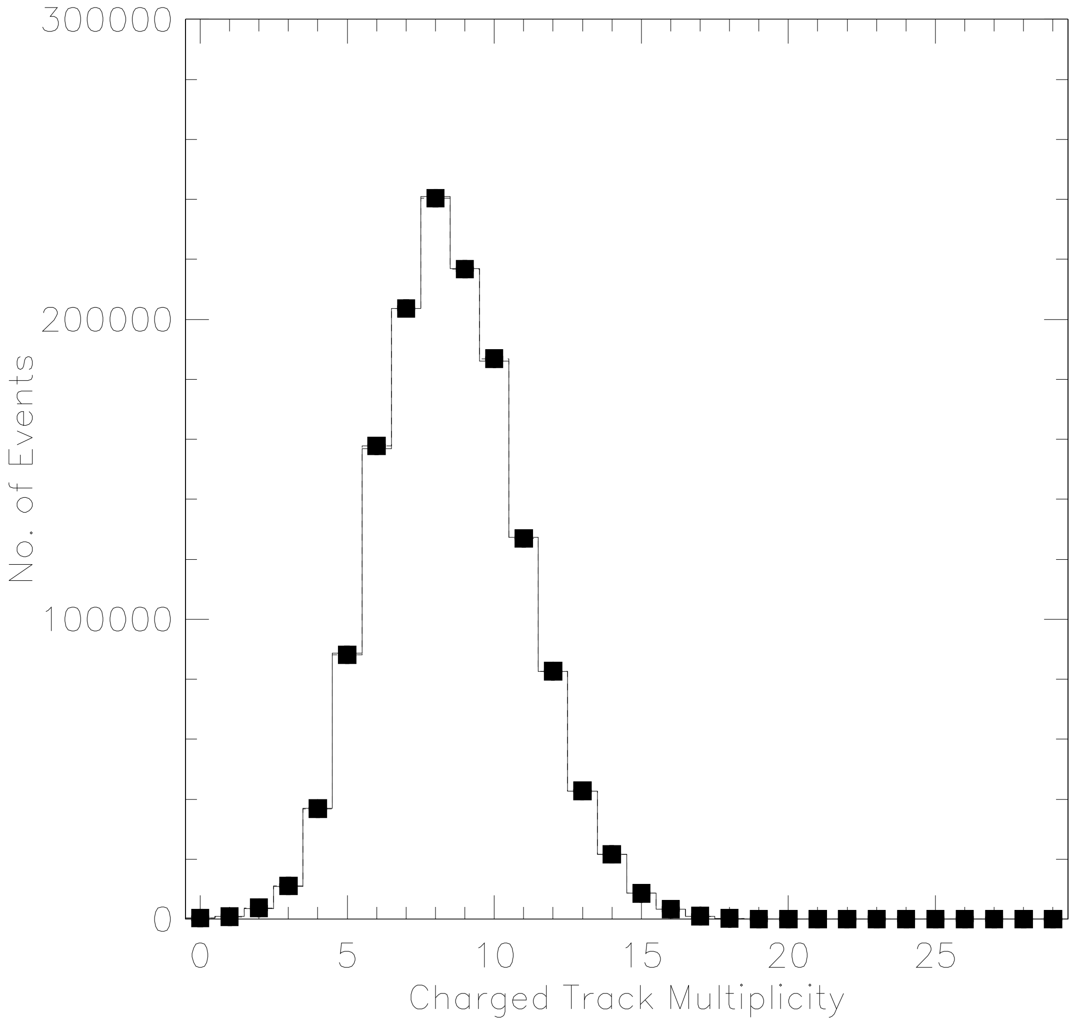

FIG. 2. The observed charge track distribution shown in Figure 1(b) is fitted with the thirteen histograms.

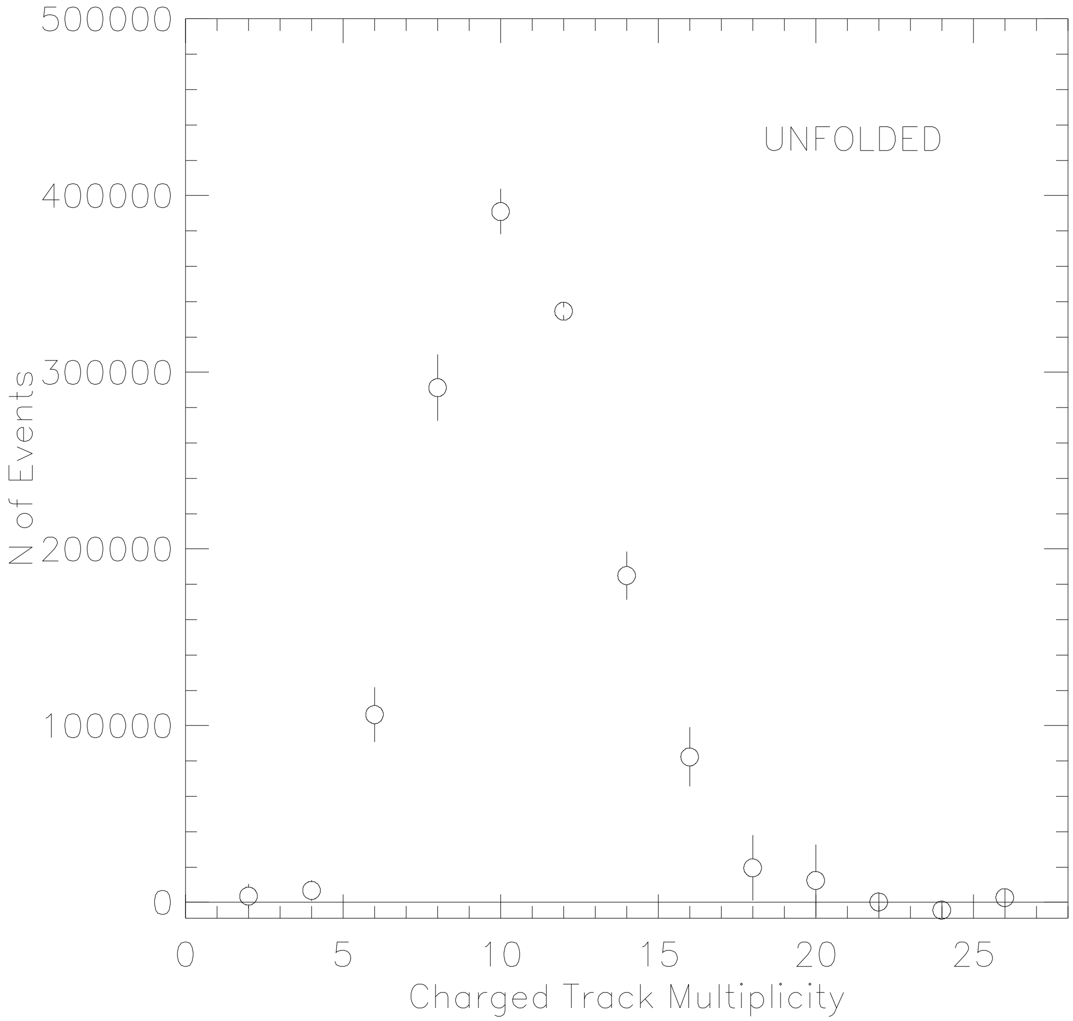

FIG. 3. Unfolded actual charged track multiplicity distribution of the $B\bar{B}$ events from the χ^2 fit. The mean charge multiplicity is 10.76 ± 0.015. The error bars for each data point are calculated by adding the statistical and systematic errors in quadrature.

where ε, n and m are the effective single track efficiency, parent and reconstructed charge multiplicities, respectively. Describing the reconstructed distributions with binomial distributions is appropriate since the effective single track efficiency ε represents the probability of finding a charged track, while the complement $1-\varepsilon$ represents the probability of not finding it. Varying these effective efficiencies by an amount corresponding to a ± 1 % variation in the tracking efficiency results in a $^{+1.8}_{-1.6}$ % change in the unfolded mean multiplicity. We assign a systematic error of 2% in the mean charge multiplicity due to tracking uncertainty.

Another source of systematic uncertainty due to tracking is the minimum momentum cut of 50 MeV/c, below which tracking efficiency in the CLEO wire chambers drops off. After varying this cut over the range of 50 MeV/c to 200 MeV/c, we assign a 0.6% systematic error from this source. The two tracking systematic errors are added linearly to give a total tracking systematic error of 2.6%

Systematic errors due to other sources are negligible. The luminosity ratio between the On-4S and Below-4S data is very well measured at CLEO, to better than 0.1% [6]. Varying this ratio by 0.1% results in a 0.1% change in the mean multiplicity. Another source of systematic uncertainty is the dip angle cut on each track. At large $|cos\theta|$ values, tracks have fewer hits in the wire chambers and the tracking efficiency drops. Varying the dip angle cut from $|cos\theta| < 0.9$ to 0.8 results in a 0.1% change in the mean multiplicity. Thus we arrive at a total systematic error of $\pm$2.6% for the measurement.

V. CONCLUSION

We have measured the charged particle multiplicity in $\Upsilon(4S)$ decays with a mean multiplicity of 10.76$\pm$0.015$\pm$0.28, where the first error is statistical and the second systematic. Assuming that 100% of $\Upsilon(4S)$ decays to $B\bar{B}$ pairs and $B\bar{B}$ production contains an equal mixture of B^+B^- and $B^0\bar{B}^0$, we obtain a mean multiplicity of 5.38$\pm$0.008$\pm$0.14 charged tracks per B meson decay, compared to the 1984 CLEO measurement of $5.50 \pm 0.03 \pm 0.15$.

Separate measurements of the charged track multiplicities in semi-leptonic and hadronic B meson decays will be forthcoming in the near future.

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