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Measurement of the Semileptonic Decay Spectrum and Branching Fraction of $\bar{B}^0$ Mesons

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Abstract

We have made a first measurement of the inclusive leptonic momentum spectrum of $\bar{B}^0$ decays using a sample of events enriched in neutral B's through a partial reconstruction of $\bar{B}^0 \to D^{*+} l^- \bar{\nu}$. This spectrum may be compared directly to the inclusive lepton spectrum in Υ(4S) events to provide a measure of difference in decay rates between neutral and charged B mesons. Using these two lepton spectra with two other CLEO measurements, we obtain the respective semileptonic branching fractions, b_0 and b_+, their ratio, and the production ratio f_{+-}/f_{00} of charged and neutral B pairs at the Υ(4S). From 2.38 fb^{-1} of data collected at the Υ(4S) resonance by the CLEO II detector, we obtain $b_+/b_0 = 0.952^{+0.117}_{-0.081} \pm 0.060$, $b_0 = (10.82 \pm 0.60 \pm 0.46)\%$, $b_+ = (10.30 \pm 0.58 \pm 0.42)\%$, and $f_{+-}/f_{00} = 1.20 \pm 0.12 \pm 0.21$. b_+/b_0 is equivalent to the ratio of charged to neutral B lifetimes, τ_+/τ_0.

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I. INTRODUCTION

There is significant motivation to know the individual semileptonic branching fractions, b_+ and b_0, of $B_u(B^-)$ and $B_d(\bar{B}^0)$. From a theoretical point of view, it is argued that a heavy quark should decay weakly without regard to the flavor of the light partner in the hadron containing it. Strictly speaking, however, weak hadronic decays are not isospin invariant; in the case of charm hadrons, the asymmetry of hadronic widths is known to be large. Some asymmetry is therefore to be expected in the lifetimes of bottom hadrons. Recent predictions for the lifetime ratio $\tau(B^-)/\tau(\bar{B}^0)$ are within 10% of unity [1]. There has also been some speculation that differences will be manifested in the shapes of the leptonic spectra [2].

The method of partial reconstruction of $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$, where the decay $D^{*+} \to D^0\pi^+$ is identified using only the π^+, has been used by CLEO II to measure both the mixing parameter χ_d [3,4] and semileptonic branching fraction b_0 [5,4] of $\bar{B}^0$. The reconstructed decay is used to *tag* a sample of events enriched in neutral B's. It is identified through the prominent peak in a reconstruction of the squared missing mass of the neutrino, $\widetilde{M}_\nu^2$.

We present here an analysis in which the partial reconstruction method is used to measure the leptonic momentum spectrum of an event sample highly enriched in neutral B mesons. This is, with minor corrections, a measurement of the inclusive leptonic spectrum from semileptonic $\bar{B}^0$ decays. It may be compared with the corresponding spectrum in Υ(4S) events, which contain a roughly equal mix of neutral and charged B's. By comparing the total rates to primary leptons in untagged and tagged events, it is possible to extract not only a value for b_0, but also for b_+ and $b_{+/0} \equiv b_+/b_0$. Assuming that the semileptonic partial widths are equal for charged and neutral B's, $b_{+/0}$ is then equal to the ratio of charged to neutral B lifetimes τ_+/τ_0.

II. DATA

The data were collected with the CLEO II detector [6] at the Cornell Electron Storage Ring (CESR) and consist of integrated luminosities of 2.38 fb^{-1} on the $\Upsilon(4S)$ resonance and 1.13 fb^{-1} taken at a center-of-mass energy which is lower by 60 MeV (continuum). All events considered in this report are required to pass our standard hadronic criteria, which require at least 3 well-fitted charged tracks, a measured energy at least 0.15 times the CM energy and an event vertex consistent with the known interaction point. The requirement on the number of charged tracks is further restricted to be at least five.

III. TAG SELECTION AND COUNTING

B decays are reconstructed using partial reconstruction of the semileptonic decay $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ (inclusion of the charge conjugate decay is implied throughout this paper). The method is described fully in Ref. [4]. This approach yields a large sample of tags by exploiting the extremely low Q value of the D^{*+} decay. In brief, the momentum of the π^+ is scaled to obtain an approximate four-momentum $(\widetilde{E}_{D^*}, \tilde{\mathbf{p}}_{D^*})$ for the D^{*+}:

$$E_{D^*} \simeq \frac{E_\pi}{E_\pi^{CM}} M_{D^*} \equiv \widetilde{E}_{D^*}$$

$$\mathbf{p}_{D^*} \simeq \mathbf{p}_\pi \times \frac{\sqrt{\widetilde{E}_{D^*} - M_{D^*}^2}}{|p_\pi|} \equiv \tilde{\mathbf{p}}_{D^*}$$

where E_π is the π^+ energy, $E_\pi^{CM} = 145$ MeV is the energy of the π^+ in the D^* rest frame, and M_{D^*} is the mass of the D^{*+}. The squared missing mass,

$$\widetilde{M}_\nu^2 \equiv (E_{\text{beam}} - \widetilde{E}_{D^*} - E_\ell)^2 - (\tilde{\mathbf{p}}_{D^*} + \mathbf{p}_\ell)^2$$

approximates the squared mass of the neutrino.

Leptons in the tag are required to have momentum between 1.4 GeV/c and 2.4 GeV/c. The lepton track must also be well-fitted and consistent with originating at the interaction point. Electrons are identified primarily by the ratio of calorimetric energy to momentum and specific ionization (dE/dx) in the drift chamber, and are allowed to fall in any fiducial region. Muons are required to penetrate at least five nuclear absorption lengths and fall within the fiducial region of the muon chambers.

Pions in the tag are required to have charge opposite to that of the lepton and momentum less than 0.190 GeV/c. It must also be consistent with originating at the interaction point and have specific ionization in the drift chamber consistent with the pion hypothesis. The $\widetilde{M}_\nu^2$ distribution obtained after continuum subtraction is shown in Figure 1.

To obtain the net number of reconstructed tag decays, we select candidates in the signal region ($\widetilde{M}_\nu^2 > -2.0$ GeV^2) and subtract estimated backgrounds. The continuum contribution is estimated using the data collected at energies off resonance, corrected for luminosity and energy differences. Background from $B\bar{B}$ events is estimated via Monte Carlo; its shape in $\widetilde{M}_\nu^2$ is largely defined by the phase space. Its normalization is obtained by matching the scale to data in the sideband region, $-20 < \widetilde{M}_\nu^2 < -4$ GeV^2. The set of Monte Carlo events used for this estimate is approximately five times the size of the data set. The statistical error due to the finite size of the Monte Carlo sample is included with the statistical error on the data and contributes approximately 10% to its magnitude. We find $22,880 \pm 277$ tags.

About 4% of tags are found to be identified more than once within the signal region because the soft pion curls and is multiply reconstructed. We account for this by increasing our statistical error by 2%.

The calculation of background under the $\widetilde{M}_\nu^2$ peaks depends on an accurate Monte Carlo simulation. To obtain a direct comparison, we analyze "wrong-sign" tags, where the lepton and pion carry the same charge and no net signal is expected. After continuum and Monte Carlo background subtractions, we obtain a net "signal" of -277 ± 211 events. This is consistent with zero, and we take as the systematic uncertainty the absolute value of the mean plus one standard deviation, which corresponds to 3.0% of the population in the signal region. We then take the uncertainty in the right sign background to be the same fraction of the estimated background in the right sign signal region.

The net number of tags, N_T, is then $22,880 \pm 283 \pm 491$.

IV. SPECTRUM OF ADDITIONAL LEPTONS

A. Selection and Counting

As each tag candidate is identified, a search is conducted for an additional lepton in the same event. To avoid confusion, the lepton used in the tag will be referred to hereafter as the "tag lepton", while the additional lepton from the remainder of the event will be called the "second lepton". It is possible for more than one "second lepton" to exist in an event.

Second leptons are required to have momentum between 0.5 GeV/c and 2.5 GeV/c. Since B^0 mixes with $\bar{B}^0$, we accept second leptons of either the same or opposite sign relative to the tag lepton. The tracking and identification criteria are matched to those used in the determination of the inclusive spectra [7]. Relative to those for the tag lepton, these include identical tracking requirements and more restricted solid angles, $|cos\theta_l| < 0.61$ for muons and $|cos\theta_l| < 0.707$ for electrons, where θ_l is the track polar angle. To eliminate multiply reconstructed tracks, a second lepton candidate is rejected if the angle between its momentum and that of the tag lepton is small, $\cos\theta_{ll} > 0.99$.

Among the tags with which a second lepton is identified, candidates are sorted in 100 MeV/c increments of the momentum of the second lepton. Electrons and muons are handled separately. For each momentum bin, we plot the distribution in $\widetilde{M}_\nu^2$ of the tag candidates. The continuum contribution is estimated and subtracted as before. We then account for the cases in which the second lepton is fake (a hadron passing lepton identification) by repeating the above analysis, selecting, instead of second leptons, tracks not identified as leptons but which pass all second lepton tracking and fiducial requirements. After estimating and subtracting the continuum part, the $\widetilde{M}_\nu^2$ distribution is scaled by the fake rate per track at the appropriate momentum [7]. After subtracting this estimated fake distribution, the background from $B\bar{B}$ events is estimated via Monte Carlo simulation, normalized in the sideband region, and subtracted. For bins with second lepton momentum in the range 2.1-2.5 GeV/c, the Monte Carlo sample is combined in order to improve the statistical significance of the background estimate. The continuum and fake-subtracted distributions are shown in Figure 2, with simulated $B\bar{B}$ background.

As with the unselected tags, where a second lepton was not required, the counting method used here relies on accurate simulation of the background shape. For each bin of second lepton momentum, we take the fractional uncertainty on the estimated background to be 3.0%, the same as that for the background on unselected tags. The resulting errors on the net numbers of tags with a second lepton are found to be 1.4%-2.1% of their values. We assign from this source an overall error of 2.1% to the final fitted number.

B. Efficiencies and corrections

The measured number of second leptons in each momentum bin is now corrected for identification efficiency. The combined efficiency for geometric acceptance, track reconstruction, and identification of a lepton in an $\Upsilon(4S)$ event is obtained for each momentum bin from ref. [7]. The systematic uncertainties on the tracking and identification efficiencies are the same as those in Ref. [4], 2.0% and 2.5%, respectively.

At this stage the efficiency-corrected spectrum of second leptons includes primary leptons from B decay and secondaries from charm semileptonic decay and from ψ decay. We now estimate and subtract the part which originates from ψ decay. Samples of $\psi \to \mu^+\mu^-$ are first reconstructed in the full data set and in the set of Monte Carlo $B\bar{B}$ events by looking at the invariant mass of an identified lepton with all other oppositely charged tracks in the same event and fitting to a Gaussian peak at the known ψ mass with a smooth background. The ratio of the fitted numbers is used to define the scaling between data and Monte Carlo; $\psi \to e^+e^-$ is not used because the measured rate depends on final state radiation, which may not be well modeled in Monte Carlo. We then find in Monte Carlo events those second leptons from ψ decay which accompany tags identified as signal with $\widetilde{M}_\nu^2 > -2.0$. The spectrum of these leptons is then scaled to obtain the estimated contribution from ψ's. It is subtracted directly from the measured efficiency-corrected spectrum. The total number of leptons from ψ's contributed to the spectrum is found to be small, 15.3 ± 3.2 (22.7 ± 4.4) for muons (electrons). The measured spectra, with backgrounds subtracted and corrected for efficiency, are shown in Figure 3.

The next two corrections apply only to the primary leptons and were found to be flat as a function of momentum. They are therefore described here but applied later, to the result of the fit to the primary spectrum described in the next subsection. The first is due to the requirements on dilepton opening angle and track multiplicity, which give a combined efficiency of $(98.9 \pm 1.1)\%$ [4]. The second correction arises from the fact that the tagging efficiency has a slight dependence on the decay charge multiplicity of the other B in an event, such that if the other decay is semileptonic, its lower average multiplicity results in a higher tag efficiency. It effectively raises the efficiency for lepton identification by $(+2.9\pm1.3)\%$ in events containing a tag. The correction was calculated for each momentum bin of the second lepton using a Monte Carlo simulation and found to be independent of second lepton momentum.

C. Spectrum Fitting

The two spectra are fitted to sums of primary and secondary spectra, in a manner identical to that used for the inclusive measurement [7]; the muon and electron spectra are fit simultaneously, constrained to the same normalization under an assumption of $e-\mu$ universality. The shapes used for fitting differ slightly between electrons and muons because the electron spectra are slightly softened due to final state radiation. The electron spectrum is fitted in the range $0.6 - 2.5$ GeV/c while the muon spectrum is fitted for $1.5 - 2.5$ GeV/c. For the shapes we use the model of Altarelli et al. ($ACCMM$) [8], which was used for the final fit of the inclusive spectrum [7]. The ratio of the $b \to u$ relative to the $b \to c$ rates is fixed to be 0.0140 ± 0.0030, the value measured in Ref. [7]. The secondary distribution is transformed from the D rest frame to the lab frame using momentum distributions of D's measured at CLEO.

The fit, shown in Figure 3, yields $2,529 \pm 102$ primary semileptonic decays ($b \to c$ and $b \to u$) in tagged events. To this number we apply the corrections described earlier for the requirements on opening angle, multiplicity, and effective tagging efficiency, to obtain a net $N_T^l = 2,484 \pm 100$. This number is divided by the number of tags to obtain b_{tag}, the average semileptonic branching fraction of the tag sample, which consists mainly of neutral B's:

$$b_{tag} = (10.86 \pm 0.46)\%.$$

The fitting procedure is also applied to the inclusive leptonic spectra presented in [7] to verify that the results are reproduced and to study correlations of systematic effects. We obtain

$$b_{incl} = (10.55 \pm 0.040)\%,$$

which is consistent with the result of [7]; there is a small difference which can be attributed to the use of a slightly different fitting range and a fixed ratio $(b \to u)/(b \to c)$. The ratio of b_{tag} and b_{incl} is

$$R \equiv \frac{b_{tag}}{b_{incl}} = 1.029 \pm 0.044.$$

D. Spectral Shape

The above measurement depends on the assumption that the inclusive leptonic spectrum from charged and neutral B decay have the same shape. With this analysis, we are in a position to test this assumption. The overall appearance of the tagged and inclusive spectra differ from each other because the primary and secondary rates are not the same; for each tag there are two opportunities to find a lepton from secondary decay and only one from primary decay, so the fraction of secondary leptons in the tagged spectrum is approximately twice that of the inclusive spectrum. Our investigation is therefore restricted to the region above 1.5 GeV/c, where nearly all of the leptons are primary.

The spectra, both tagged and inclusive, electrons and muons, are first corrected for the estimated contribution from secondary leptons found by fitting. The corrected tagged spectra of electrons and muons are then divided by the corresponding inclusive spectra, bin-by-bin. The resulting distributions are fitted to a constant function in the range 1.5-2.4 GeV/c (Figure 4). If the distributions are flat, as appears to be the case, then the fitted constant is equal to the parameter R presented in the previous section. The fits yield $R = 1.012 \pm 0.061$ (1.035 ± 0.071) for electrons (muons), for a weighted average of

$$R = 1.022 \pm 0.046.$$

This is in good agreement with the result from the previous section. The statistical significance of this measurement is nearly identical to that of the measurement by fitting because it is dominated in both cases by the portion of the spectrum above 1.5 GeV/c.

E. Systematic Errors

The uncertainties on b_{tag} and b_{incl} are dominated by the assembling and fitting of the lepton spectra (numerator), rather than the determination of the number of events in the data sample (denominator). Because the procedures for obtaining b_{tag} and b_{incl} have been made as nearly identical as possible, many of their systematic errors are highly correlated and will cancel in obtaining their ratio R. Among the sources of these are lepton tracking and identification efficiencies, subtraction of the ψ contribution, fake efficiencies, spectral shapes for fitting, and the fraction of $b \to u$ in the spectrum.

To estimate the effects of variations in the ψ contribution, fake efficiencies and the $b \to u$ fraction, we repeated the fits, adjusting each parameter upward and downward by the estimated uncertainty.

To assess the effect of a difference in the shape of the spectra from the shape used, the fitting was repeated with varying primary and secondary shapes. Only shapes which give reasonable fits to the inclusive spectrum of [7] are used. For the primary spectrum we include a variation (ISGW**) on the model of Isgur et al. [9] in which the fractional contribution of $B \to D^{**} l\nu$ to semileptonic decays is fixed for each fit in the range $(23 \pm 1)\%$ [7], and compare the results to those from ACCMM. For the secondary spectrum we use the method and shapes used in Ref. [3], where the shape is defined in terms of four parameters which can be varied within given bounds. These shapes are used only to determine the magnitude of the uncertainty. Each of the four parameters is varied within its bounds, and the error is taken to be the maximum excursion of the fit from the mean. The net error from the secondary spectral shape is the quadratic sum of these four errors. The method used in Ref. [7], where the effect of the secondary shape was tested by shifting it 50 MeV/c upward and downward, was found to have a significantly smaller effect on the branching fractions and on R.

The sources and effects are summarized in Table I. For the value obtained by fitting, the net uncertainty on R from all correlated sources is 1.7%. Systematic effects which apply to b_{tag} but not to b_{incl} include the difference in tagging efficiencies between events which do and do not contain second leptons and the effect of the tag on event selection. These contribute 1.3% and 1.1%, respectively. The uncertainty from the background estimate for the partial reconstruction tag cancels approximately in taking the ratio to obtain b_{tag}, and we assign an overall uncertainty of 1% to b_{tag} from this source. The net uncertainty on R from all sources is 2.6%.

The method of direct bin-by-bin ratios is independent of any assumptions about the shape of the primary spectrum. The net systematic error on the value of R is therefore somewhat smaller, 2.4%.

V. BRANCHING FRACTIONS

A. Extraction of b_0 and b_+

The measurements shown above were made on event samples containing both neutral and charged B's. To extract b_0, b_+, and their ratio $b_{+/0} \equiv \frac{b_+}{b_0}$, we first express the measured quantities b_{tag} and b_{incl} as

$$b_{tag} = f_{0,tag} b_0 + f_{+,tag} b_+, \tag{1}$$
$$b_{incl} = f_{00} b_0 + f_{+-} b_+. \tag{2}$$

where $f_{0,tag}$ and $f_{+,tag}$ are the fractions of tags which are from neutral and charged B's, respectively; some charged B's are present among the tags from decays of the type $B \to D^{*+}Xl^-\bar{\nu}$, where X consists of at least one pion. The fraction f^{**} of such decays among our tags has been measured using decays identified using the same kinematic requirements with the addition of full D^{*+} reconstruction, and is found to be 0.14 ± 0.08 [10]. The relative contributions from charged and neutral B's is determined using isospin conservation in the fragmentation of the hadronic part of the final state; if b_0 and b_+ are equal and the charged and neutral B's decay to $D^*Xl^-\bar{\nu}$ at the same rates, the rate to states where X is a charged pion is double that of the rate where it is a neutral pion. In other words, $B^- \to D^{*+}\pi^-l^-\bar{\nu}$ contributes to f^{**} at twice the rate of $\bar{B}^0 \to D^{*+}\pi^0 l^-\bar{\nu}$, weighted by the respective production rates and semileptonic branching fractions [3], or a fraction $\frac{2\alpha}{1+2\alpha}$ ($\alpha \equiv \frac{f_{+-}b_+}{f_{00}b_0}$), so that

$$f_{+,tag} = f^{**}\frac{2\alpha}{1+2\alpha}, \tag{3}$$

$$f_{0,tag} = 1 - f_{+,tag} = 1 - f^{**}\frac{2\alpha}{1+2\alpha.} \tag{4}$$

If we use the CLEO II measurement $\alpha = \frac{\mathcal{B}(\Upsilon(4S)\to B^+B^-, B^-\to D^{*0}l^-\bar{\nu})}{\mathcal{B}(\Upsilon(4S)\to B^0\bar{B}^0, \bar{B}^0\to D^{*+}l^-\bar{\nu})} = 1.14 \pm 0.14 \pm 0.13$ [11], then $f_{0,tag} = (90.3 \pm 5.5)\%$ and $f_{+,tag} = (9.7 \pm 5.5)\%$. Expressing f_{00} in terms of α and $b_{+/0}$

$$f_{00} = \left[1 + \frac{\alpha}{b_{+/0}}\right]^{-1} \tag{5}$$

and taking the ratio of (1) and (2) with substitutions from (3), (4), and (5),

$$\begin{aligned} R = \frac{b_{tag}}{b_{incl}} &= \frac{f_{0,tag} + f_{+,tag}b_{+/0}}{f_{00}(1+\alpha)} \\ &= \frac{(1 - f^{**}\frac{2\alpha}{1+2\alpha} + f^{**}b_{+/0}\frac{2\alpha}{1+2\alpha})(1 + \frac{\alpha}{b_{+/0}})}{1+\alpha}, \end{aligned} \tag{6}$$

leads to a quadratic equation in $b_{+/0}$ which is readily solved. From this it is straightforward to obtain values for f_{00} as well as b_0 and b_+:

$$\begin{aligned} b_0 &= \frac{b_{tag}f_{+-} - b_{incl}f_{+,tag}}{f_{0,tag}f_{+-} - f_{+,tag}f_{00}} = b_{incl} \cdot \frac{Rf_{+-} - f_{+,tag}}{f_{0,tag}f_{+-} - f_{+,tag}f_{00}}, \\ b_+ &= \frac{b_{incl}f_{0,tag} - b_{tag}f_{00}}{f_{0,tag}f_{+-} - f_{+,tag}f_{00}} = b_{incl} \cdot \frac{f_{0,tag} - Rf_{00}}{f_{0,tag}f_{+-} - f_{+,tag}f_{00}}. \end{aligned}$$

The quantities needed to determine b_0, b_+, and $b_{+/0}$ are R (measured here), b_{incl} (measured in [7], refitted here), f^{**} (measured in [10]), and α (measured in [11]).

B. Result

As has been described, the spectrum of tags with second leptons has been compared to the inclusive lepton spectrum in two ways, through fitting and through a bin-by-bin comparison, to arrive at the respective values

$$R = 1.029 \pm 0.044 \pm 0.027$$
$$\text{and} \quad R = 1.022 \pm 0.046 \pm 0.025.$$

Because the two methods are applied to the same spectra, they are expected to give similar results, and our observation is that this is indeed the case. We now proceed with the result from the second method, which is preferred because it is independent of the shape of the primary spectrum. Using

$$\begin{aligned} f^{**} &= 0.14 \pm 0.08, \\ \alpha &= 1.14 \pm 0.19, \\ b_{incl} &= (10.55 \pm 0.04 \pm 0.30)\%, \end{aligned}$$

we obtain,

$$\begin{aligned} b_{+/0} &= 0.952^{+0.117+0.060}_{-0.081-0.051}, \\ b_0 &= (10.82 \pm 0.60 \pm 0.46)\%, \\ b_+ &= (10.30 \pm 0.58 \pm 0.42)\%, \\ f_{+-}/f_{00} &= 1.20 \pm 0.12 \pm 0.21 \end{aligned}$$

where in each case the first error is statistical and the second systematic. The last number may be equivalently expressed as $f_{00} = 0.455 \pm 0.028 \pm 0.050$. The determinations of b_0, b_+, $b_{+/0}$, and f_{+-}/f_{00} involve several correlated inputs which must be accounted for in computing the uncertainties. The errors are obtained numerically; the values of b_0, b_+, $b_{+/0}$, and f_{00} are calculated from the input parameters which are varied about their means, and the errors are taken to be the RMS deviation of the resulting values from those determined at the mean values of the parameters. They are asymmetric due to nonlinear dependencies on the input parameters. All of the statistical uncertainties are defined by the uncertainty in R. The dominant contributors to the systematic uncertainties are R for $b_{+/0}$, both R and b_{incl} for b_0 and b_+, and α for f_{00}. The statistical errors on b_0 and b_+, are highly correlated because the principal inputs, R and b_{incl}, represent different linear combinations of b_0 and b_+ with very different statistical uncertainties. This is illustrated in Figure 5, which shows the bands in the $b_0 - b_+$ plane defined by the two measurements.

VI. CONCLUSION AND SUMMARY

The electronic and muonic momentum spectra have been measured in a sample of events enriched in neutral B's using partial reconstruction tags. By comparing these spectra to the inclusive momentum spectra in $\Upsilon(4S)$ events, we investigate differences between neutral and charged B's in rates of primary semileptonic decay and spectral shapes at high momenta. Because of the high purity of $\bar{B}^0$ in our tagged sample, the results are insensitive to the production fraction of charged and neutral B's in $\Upsilon(4S)$ events.

Two methods are used to evaluate the rates. First, both tagged and inclusive spectra are fitted with the same spectral functions, to obtain a ratio of rates for primary B decay in the respective event samples. Second, the same ratio is calculated bin-by-bin in momentum above 1.5 GeV/c and fitted to a constant. This second analysis not only gives a ratio of rates which is insensitive to the actual shape of the primary spectrum, it may also be used to identify differences in shape between the tagged and inclusive spectra.

The distribution of the ratio as a function of momentum in the range 1.5-2.4 GeV/c is consistent with being flat. We thus conclude that we have no evidence for differences between neutral and charged B semileptonic decay spectra in this region.

The two methods yield consistent values, and we report the branching fractions using the result of the bin-by-bin method, which is independent of the shape of the primary spectrum:

$$\begin{aligned} b_{+/0} &= 0.952^{+0.117+0.060}_{-0.081-0.051}, \\ b_0 &= (10.82 \pm 0.60 \pm 0.46)\%, \\ b_+ &= (10.30 \pm 0.58 \pm 0.42)\%, \\ f_{+-}/f_{00} &= 1.20 \pm 0.12 \pm 0.21, \\ (f_{00} &= 0.455 \pm 0.028 \pm 0.050). \end{aligned}$$

These are consistent with our previous results [5],

$$\begin{aligned} b_{+/0} &= 0.93 \pm 0.18 \pm 0.12, \\ b_0 &= (10.9 \pm 0.7 \pm 1.1)\%, \\ b_+ &= (10.1 \pm 1.8 \pm 1.5)\%. \end{aligned}$$

Our previous result for f_{+-}/f_{00} [11],

$$f_{+-}/f_{00} = 1.04 \pm 0.13 \pm 0.16,$$

was obtained using our measurement of α with an average lifetime ratio $\tau_+/\tau_0 = 1.10 \pm 0.11$, which was based on measurements at LEP and CDF [12]. The new measurement reported here has been obtained using CLEO data exclusively.

VII. ACKNOWLEDGEMENT

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TABLES

TABLE I. Correlated systematic errors on b_{tag}, b_{incl} and R.

Source	$\frac{\sigma_{sys}}{value}$(%) or procedure	$\frac{\delta(b_{tag})}{b_{tag}}$(%)	$\frac{\delta(b_{incl})}{b_{incl}}$(%)	$\frac{\delta(R)}{R}$(%)
(2^{nd}) lepton, tracking efficiency	2.0	2.0	2.0	–
(2^{nd}) lepton, ID efficiency	2.5	2.5	2.5	–
ψ contribution	30	0.3	0.4 [7]	0.2
Fake efficiency f_e	50	0.2	0.3 [7]	0.2
Fake efficiency f_μ	25	0.1	0.2 [7]	0.2
secondary spectrum	as in Ref. [3]	2.0	0.6	1.4
primary spectrum	ISGW** [7]	4.6	3.7	0.9
$(b \to u)/(b \to c)$	21	0.1	0.1	–
Overall		6.0	5.0	1.7

FIGURES

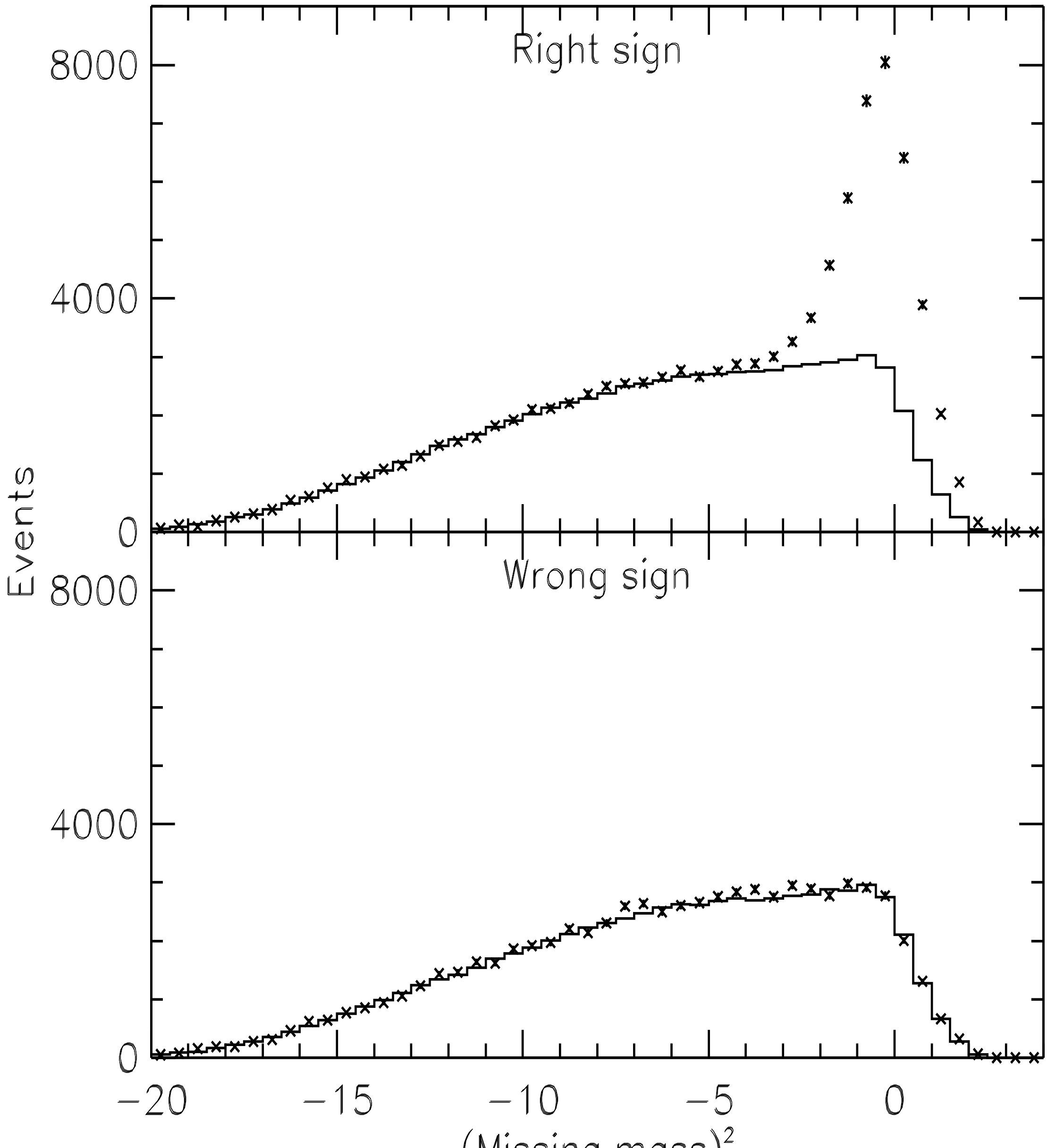
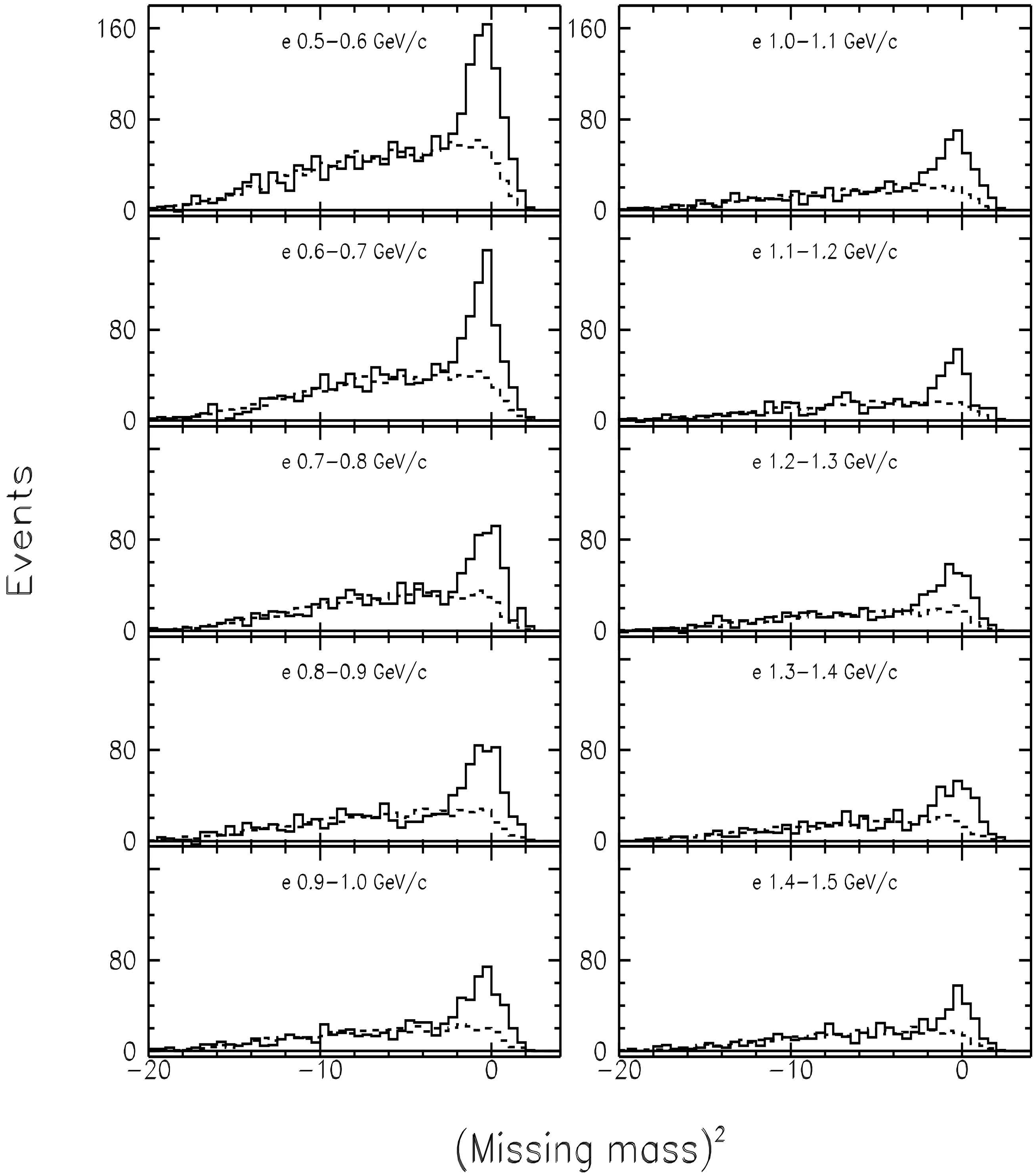
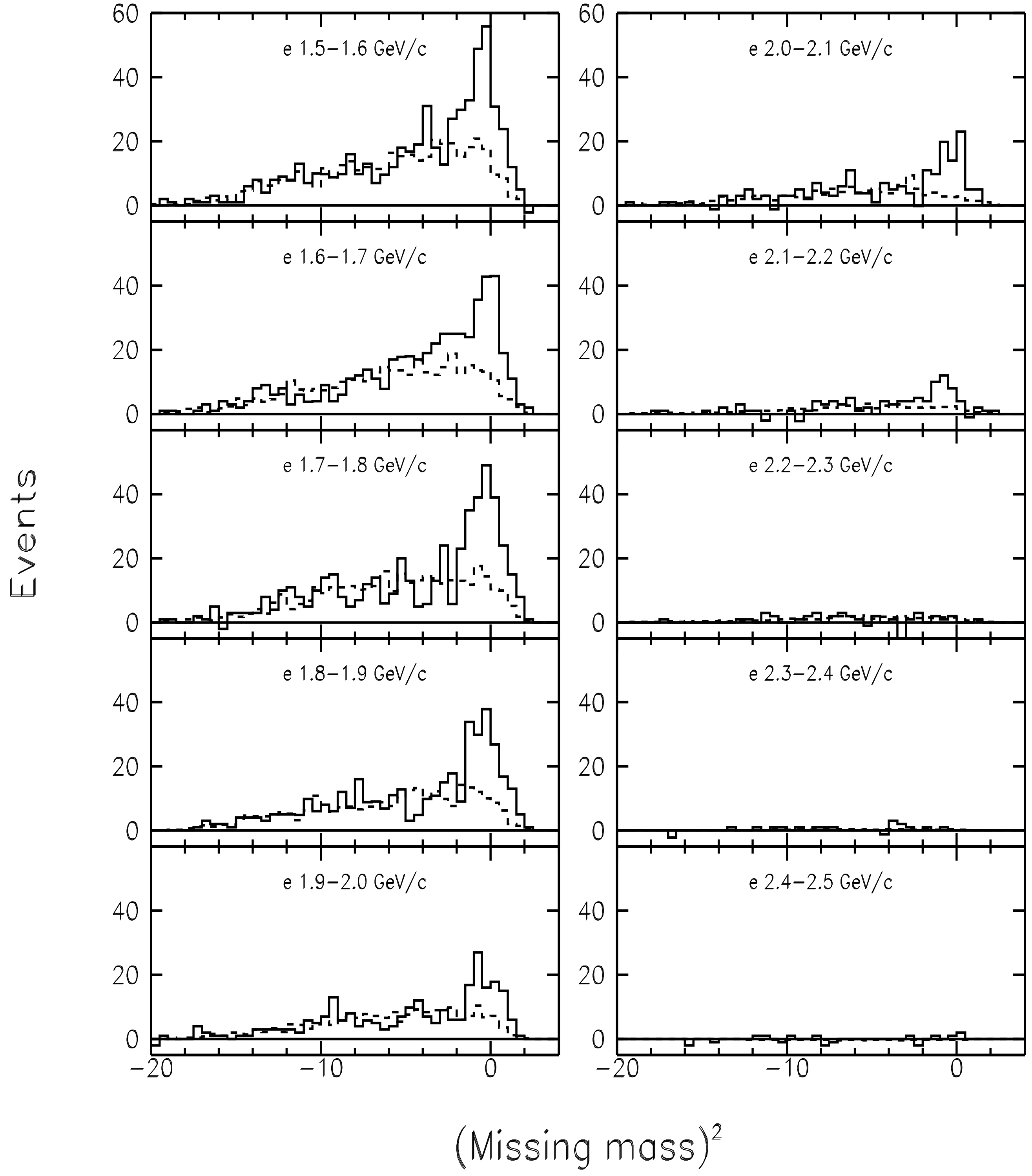


FIG. 1. Continuum-subtracted $\widetilde{M}_\nu^2$ distributions (crosses, with error bars), with backgrounds estimated via Monte Carlo simulation (solid histograms): (a) opposite-sign candidates, (b) same-sign candidates.


Events
e 0.5−0.6 GeV/c
e 0.6−0.7 GeV/c
e 0.7−0.8 GeV/c
e 0.8−0.9 GeV/c
e 0.9−1.0 GeV/c
e 1.0−1.1 GeV/c
e 1.1−1.2 GeV/c
e 1.2−1.3 GeV/c
e 1.3−1.4 GeV/c
e 1.4−1.5 GeV/c
160
80
0
−20
−10
0
(Missing mass)^2


e 1.5−1.6 GeV/c
e 1.6−1.7 GeV/c
e 1.7−1.8 GeV/c
e 1.8−1.9 GeV/c
e 1.9−2.0 GeV/c
e 2.0−2.1 GeV/c
e 2.1−2.2 GeV/c
e 2.2−2.3 GeV/c
e 2.3−2.4 GeV/c
e 2.4−2.5 GeV/c
Events
(Missing mass)^2
60
40
20
0
−20
−10

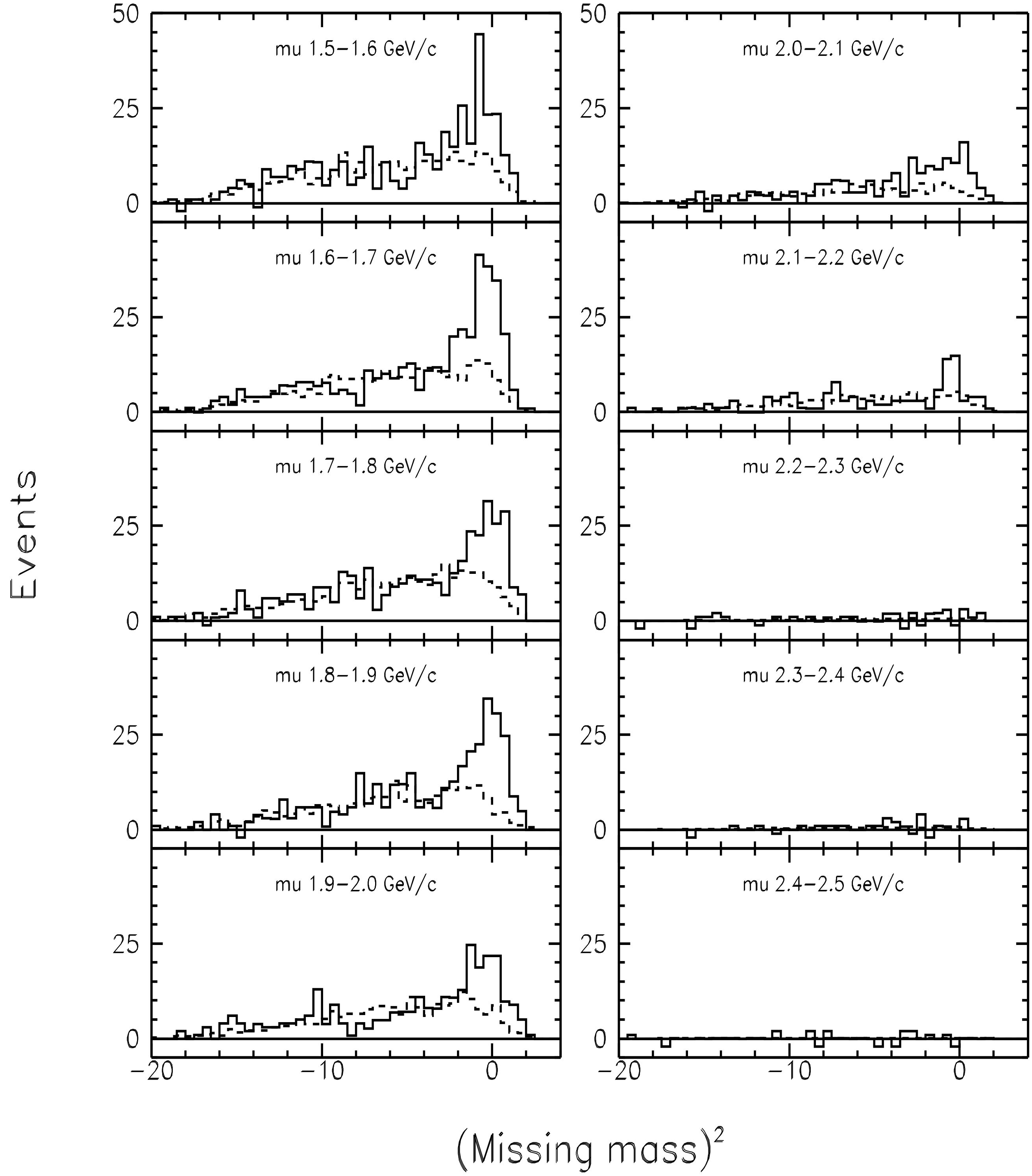


FIG. 2. $\widetilde{M}_{\nu}^2$ distributions of events containing a second lepton, in 100 MeV/c bins of second lepton momentum, electrons (0.5-2.5 MeV/c) and muons (1.5-2.5 MeV/c). Data are shown corrected for continuum and fake second leptons (solid), with backgrounds estimated via Monte Carlo simulation (dashed).

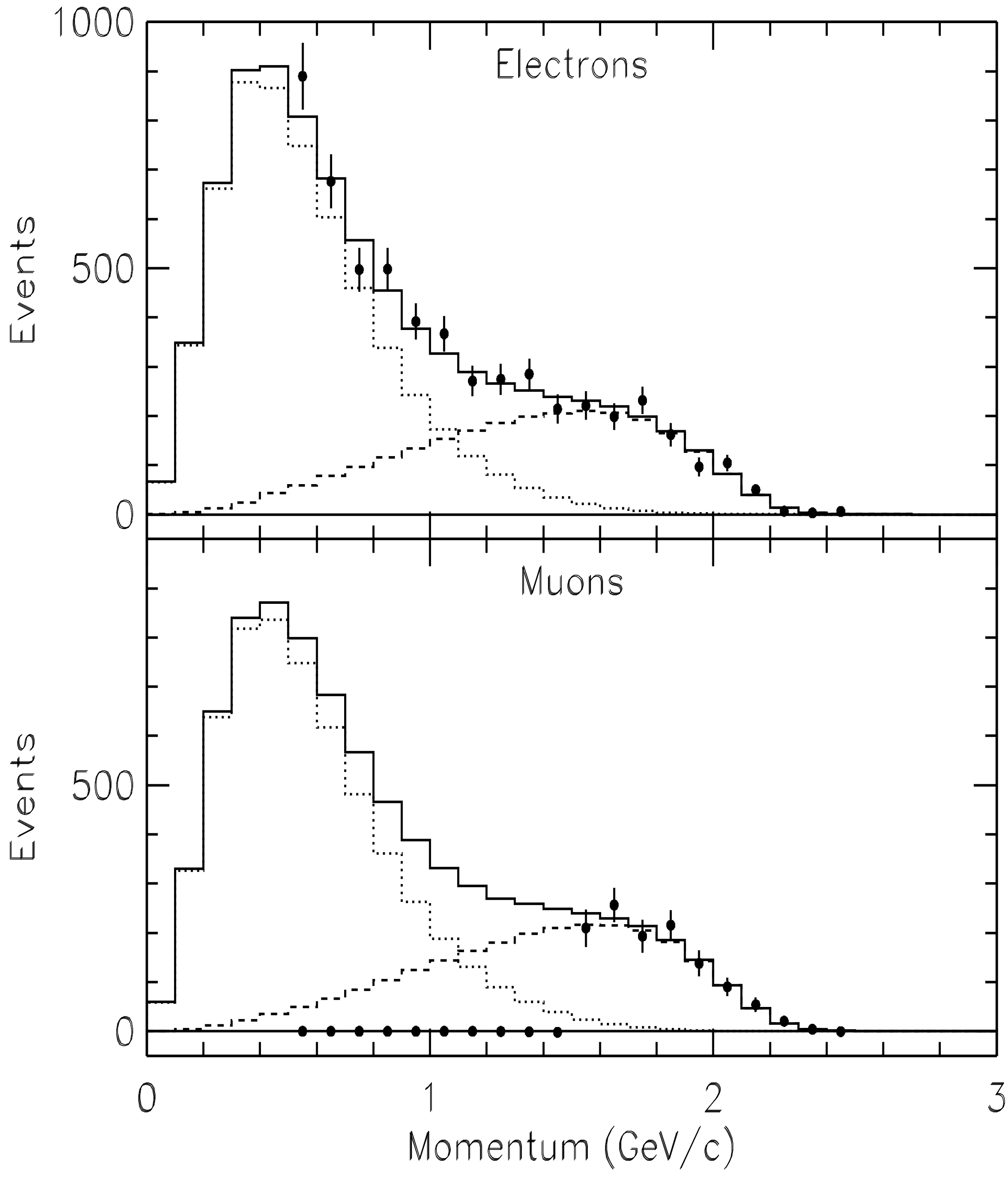


FIG. 3. Measured spectrum of second leptons, corrected for efficiency and with ψ contribution subtracted, shown with fit to primary (dashed) and secondary (dotted) spectra.

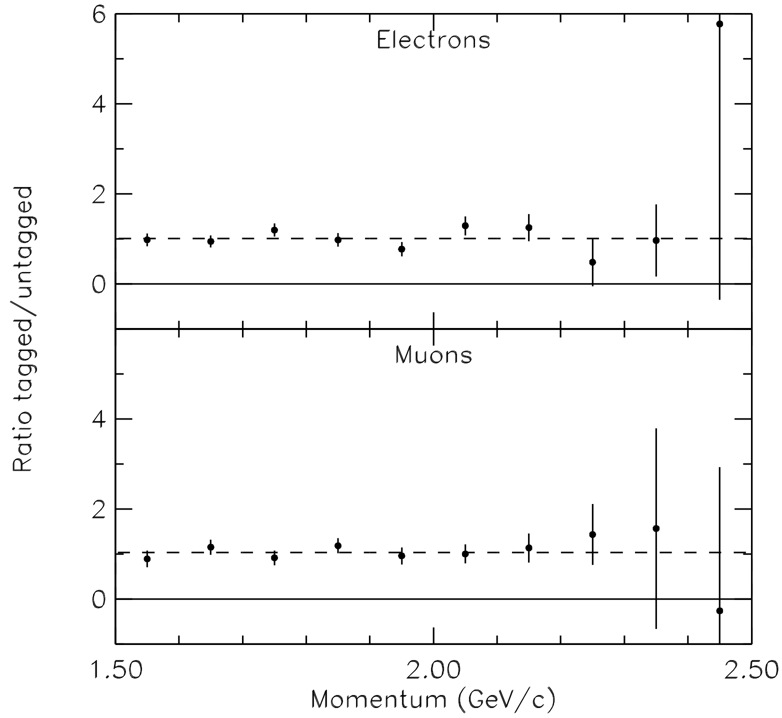


FIG. 4. Bin-by-bin ratio of semileptonic rates from partial reconstruction and inclusive analyses, with fits to a constant (dashed line) in the range 1.5-2.4 GeV/c, electrons (top) and muons (bottom).

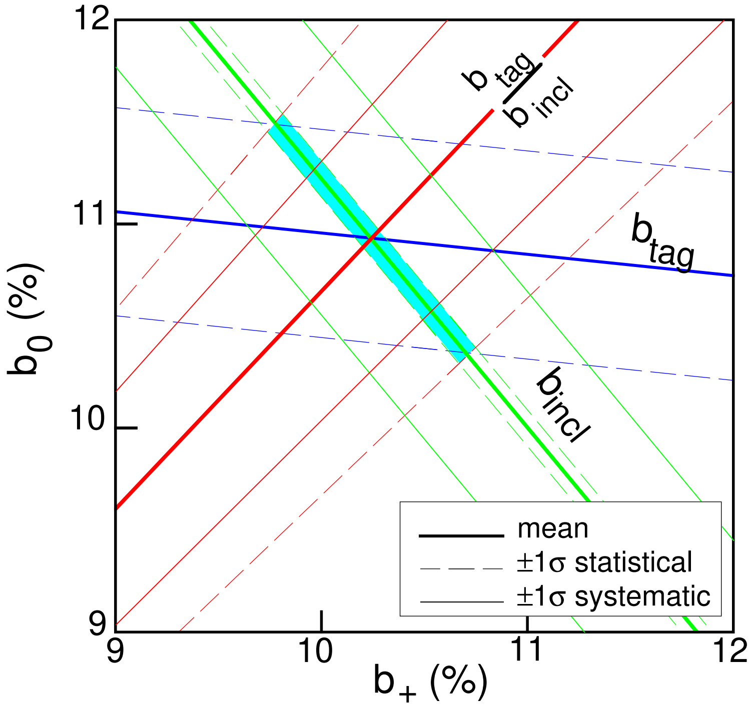


FIG. 5. Allowed region in b_0 and b_+ defined by our measurements. Lines correspond to mean values of b_{incl} and R and deviations by 1σ, statistical and systematic. The shaded area is the intersection of the bands which are within one statistical deviation. Also shown is the line and statistical deviation defined by b_{tag}.