CLEO-CONF 05-6
LP2005-432

A Preliminary Study of Weak Annihilation in $B \to X_u \ell \nu$ decay at CLEO

N. E. Adam,[1] J. P. Alexander,[1] K. Berkelman,[1] D. G. Cassel,[1] V. Crede,[1] J. E. Duboscq,[1] K. M. Ecklund,[1] R. Ehrlich,[1] L. Fields,[1] R. S. Galik,[1] L. Gibbons,[1] B. Gittelman,[1] R. Gray,[1] S. W. Gray,[1] D. L. Hartill,[1] B. K. Heltsley,[1] D. Hertz,[1] C. D. Jones,[1] J. Kandaswamy,[1] D. L. Kreinick,[1] V. E. Kuznetsov,[1] H. Mahlke-Krüger,[1] T. O. Meyer,[1] P. U. E. Onyisi,[1] J. R. Patterson,[1] D. Peterson,[1] E. A. Phillips,[1] J. Pivarski,[1] D. Riley,[1] A. Ryd,[1] A. J. Sadoff,[1] H. Schwarthoff,[1] X. Shi,[1] M. R. Shepherd,[1] S. Stroiney,[1] W. M. Sun,[1] D. Urner,[1] T. Wilksen,[1] K. M. Weaver,[1] M. Weinberger,[1] S. B. Athar,[2] P. Avery,[2] L. Breva-Newell,[2] R. Patel,[2] V. Potlia,[2] H. Stoeck,[2] J. Yelton,[2] P. Rubin,[3] C. Cawlfield,[4] B. I. Eisenstein,[4] G. D. Gollin,[4] I. Karliner,[4] D. Kim,[4] N. Lowrey,[4] P. Naik,[4] C. Sedlack,[4] M. Selen,[4] E. J. White,[4] J. Williams,[4] J. Wiss,[4] K. W. Edwards,[5] D. Besson,[6] T. K. Pedlar,[7] D. Cronin-Hennessy,[8] K. Y. Gao,[8] D. T. Gong,[8] J. Hietala,[8] Y. Kubota,[8] T. Klein,[8] B. W. Lang,[8] S. Z. Li,[8] R. Poling,[8] A. W. Scott,[8] A. Smith,[8] S. Dobbs,[9] Z. Metreveli,[9] K. K. Seth,[9] A. Tomaradze,[9] P. Zweber,[9] J. Ernst,[10] K. Arms,[11] H. Severini,[12] D. M. Asner,[13] S. A. Dytman,[13] W. Love,[13] S. Mehrabyan,[13] J. A. Mueller,[13] V. Savinov,[13] Z. Li,[14] A. Lopez,[14] H. Mendez,[14] J. Ramirez,[14] G. S. Huang,[15] D. H. Miller,[15] V. Pavlunin,[15] B. Sanghi,[15] I. P. J. Shipsey,[15] G. S. Adams,[16] M. Cravey,[16] J. P. Cummings,[16] I. Danko,[16] J. Napolitano,[16] Q. He,[17] H. Muramatsu,[17] C. S. Park,[17] E. H. Thorndike,[17] T. E. Coan,[18] Y. S. Gao,[18] F. Liu,[18] R. Stroynowski,[18] M. Artuso,[19] C. Boulahouache,[19] S. Blusk,[19] J. Butt,[19] O. Dorjkhaidav,[19] J. Li,[19] N. Menaa,[19] R. Mountain,[19] R. Nandakumar,[19] K. Randrianarivony,[19] R. Redjimi,[19] R. Sia,[19] T. Skwarnicki,[19] S. Stone,[19] J. C. Wang,[19] K. Zhang,[19] S. E. Csorna,[20] G. Bonvicini,[21] D. Cinabro,[21] M. Dubrovin,[21] A. Bornheim,[22] S. P. Pappas,[22] A. J. Weinstein,[22] R. A. Briere,[23] G. P. Chen,[23] J. Chen,[23] T. Ferguson,[23] G. Tatishvili,[23] H. Vogel,[23] M. E. Watkins,[23] and J. L. Rosner[24]

(CLEO Collaboration)

[1]Cornell University, Ithaca, New York 14853
[2]University of Florida, Gainesville, Florida 32611
[3]George Mason University, Fairfax, Virginia 22030
[4]University of Illinois, Urbana-Champaign, Illinois 61801
[5]Carleton University, Ottawa, Ontario, Canada K1S 5B6 and the Institute of Particle Physics, Canada
[6]University of Kansas, Lawrence, Kansas 66045
[7]Luther College, Decorah, Iowa 52101
[8]University of Minnesota, Minneapolis, Minnesota 55455
[9]Northwestern University, Evanston, Illinois 60208
[10]State University of New York at Albany, Albany, New York 12222
[11]Ohio State University, Columbus, Ohio 43210
[12]University of Oklahoma, Norman, Oklahoma 73019
[13]University of Pittsburgh, Pittsburgh, Pennsylvania 15260
[14]University of Puerto Rico, Mayaguez, Puerto Rico 00681
[15]Purdue University, West Lafayette, Indiana 47907

[16]*Rensselaer Polytechnic Institute, Troy, New York 12180*
[17]*University of Rochester, Rochester, New York 14627*
[18]*Southern Methodist University, Dallas, Texas 75275*
[19]*Syracuse University, Syracuse, New York 13244*
[20]*Vanderbilt University, Nashville, Tennessee 37235*
[21]*Wayne State University, Detroit, Michigan 48202*
[22]*California Institute of Technology, Pasadena, California 91125*
[23]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*
[24]*Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637*
(Dated: June 24, 2005)

Abstract

We present preliminary results from CLEO on an investigation of weak annihilation in $B \to X_u \ell \nu$ decay. This work is based on 9.7 fb^{-1} of data collected with the CLEO II and CLEO II.V detectors at the $\Upsilon(4S)$ resonance.

The element V_{ub} of the Cabbibo-Kobayashi-Maskawa (CKM) matrix [1] remains one of the most poorly constrained parameters of that matrix. Its magnitude, $|V_{ub}|$, plays a central role in unitarity tests of the CKM matrix, which combine inputs from CP–conserving processes in the B meson system and CP–violating processes in the K and B systems to test the internal consistency of the Standard Model's CKM framework. These tests in turn factor into precision searches for signs of physics beyond the Standard Model.

An accurate determination of $|V_{ub}|$ with well-understood uncertainties remains one of the fundamental priorities for heavy flavor physics. Over the past few years, tremendous progress has been made in inclusive determinations of $|V_{ub}|$ both experimentally, with the use of fully- and partially-tagged B meson samples at BaBar [2] and Belle [3], and theoretically, with the quantitative evaluation of leading and subleading contributions to calculations of the partial $B \to X_u \ell \nu$ width in restricted regions of phase space [4–8]. However, several important issues remain, one of which concerns the size of the "Weak Annihilation" (WA) contribution [9–11] to the total $b \to u \ell \nu$ rate.

The term Weak Annihilation describes a particular four-quark operator that arises at order $(\Lambda/M_B)^3$ in the heavy quark expansion for the charmless, semileptonic B partial width. Its contribution to the total $b \to u\,\ell\,\nu$ rate is expected to be at the few percent level; a typical estimate [10, 11] is

$$\Gamma_{\mathrm{WA}}/\Gamma_{b\to u} \approx 0.03 \left(\frac{f_B}{0.2\ \mathrm{GeV}}\right)^2 \left(\frac{B_2 - B_1}{0.1}\right). \tag{1}$$

The difference of the non-perturbative matrix elements B_2 and B_1 parameterizes the violation of QCD factorization necessary to make the WA contribution non-zero, but little is known about the scale (0.1 in the above estimate) of this violation since it is fundamentally non-perturbative. WA is also expected to have a non-trivial distribution across phase space,

$$\frac{d\,\Gamma_{\mathrm{WA}}}{d\,q^2} \sim \delta(q^2 - m_b^2), \tag{2}$$

where q^2 is the square of the hadronic momentum transfer in the decay. Thus while the contribution to the total rate may in fact be small, the *relative* importance of WA can be magnified by the hard kinematic cuts typically required to isolate the $b \to u$ signal from a very large $b \to c$ background. Traditional analyses in restricted regions of the full $b \to u$ phase space (which normally include the high q^2 region) can therefore become quite sensitive to the unknown contribution from WA. Independently limiting the contribution from WA is therefore an important element in the precision extraction of $|V_{ub}|$. The CLEO analysis [12] described here places constraints on the size of these effects by fitting the q^2 spectrum in semileptonic B decays.

We use the 9.7 fb^{-1} of data collected at the $\Upsilon(4S)$ resonance with the CLEO II [13] and CLEO II.V [14] detectors, and identify events with leptons (electrons and muons) above 1.5 GeV. We infer the q^2 value for the signal semileptonic decay using event selection and reconstruction based on the method of neutrino reconstruction that has been employed in previous CLEO studies of inclusive semileptonic B decay [15, 16]. The event selection procedure, similar to that in these previous works, will be described in depth in a forthcoming publication. Here we focus on the search for a contribution, beyond the standard "shape function" contribution, to $B \to X_u \ell \nu$ decay that is concentrated at high q^2. This scenario would result in the largest bias in $|V_{ub}|$ from a lepton momentum endpoint analysis or the restriction of phase space to large q^2.

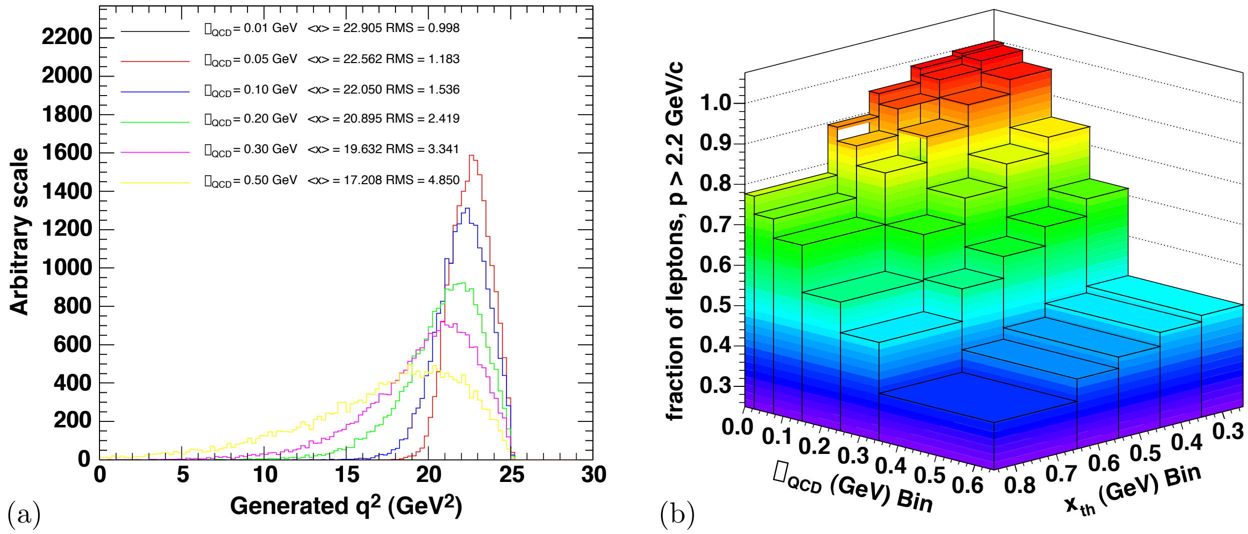

FIG. 1: Generator-level distributions for different WA Monte Carlo samples. Fig. (a) shows the q^2 distribution for six different values of the roll-off Λ with the choice $x_0 = 500$ MeV. Fig. (b) shows, for each WA sample, the fraction $f_{2.2}$ of the WA rate that lies above an idealized lepton energy cut at 2.2 GeV. (Each bin corresponds to a WA sample, and the bin content records the corresponding value for $f_{2.2}$.)

After selecting events with high momentum leptons and with characteristics that enhance the association of the missing event momentum ($\vec{p}_{\rm miss}$) with the neutrino momentum, we reconstruct $q^2 = (p_\ell + p_\nu)^2$, with $p_\nu = (|\vec{p}_{\rm miss}|, \vec{p}_{\rm miss})$. We then fit the observed q^2 spectra from three separate lepton momentum intervals to search for a concentrated enhancement in rate near the point of zero hadronic recoil (large q^2). The lowest lepton momentum bin ($1.5 < |\vec{p}_\ell| \leq 2.0\,{\rm GeV}/c$) effectively determines the background $B \to X_c \ell \nu$ normalization, the middle ($2.0 < |\vec{p}_\ell| \leq 2.2\,{\rm GeV}/c$) and highest ($|\vec{p}_\ell| > 2.2\,{\rm GeV}/c$) bins determine the total $B \to X_u \ell \nu$ yield, while the highest bin offers the greatest sensitivity to processes consistent with WA.

We model the dominant $b \to c\,\ell\,\nu$ background with the standard CLEO model of B decay, with events reweighted to reflect improvements in measured exclusive semileptonic form factors. Continuum $e^+e^- \to q\bar{q}$ backgrounds are obtained from a separate data sample collected just below $B\bar{B}$ threshold. Fake lepton contributions, in which hadrons are misidentified as leptons, are obtained by combining a sample of nonleptonic events with measured hadronic faking rates – under 0.1% for a hadron to fake an electron and about 1% to fake a muon.

We model the $b \to u\,\ell\,\nu$ component as the sum of (i) a hybrid model that combines the HQET-based approach described by DeFazio and Neubert [17] with known exclusive resonances, and (ii) a simple model for WA that respects the kinematics implied by Eqn 2. The latter model is based on a simplified intuitive picture where the "valence" quarks in the B meson annihilate and a soft non-perturbative hadronic system X_u materializes in the debris. In this formulation, the lepton-neutrino pair carries most of the energy ($q^2 \sim M_B^2$), while the hadronic system has kinematics at the non-perturbative scale $\Lambda_{\rm QCD}$. Our Monte Carlo event generator implements this description as follows: we introduce a simple probability density function (pdf) for the hadronic kinematics that is flat out to some cutoff x_0, and then begins an exponential roll-off with slope Λ. A WA decay is generated by first

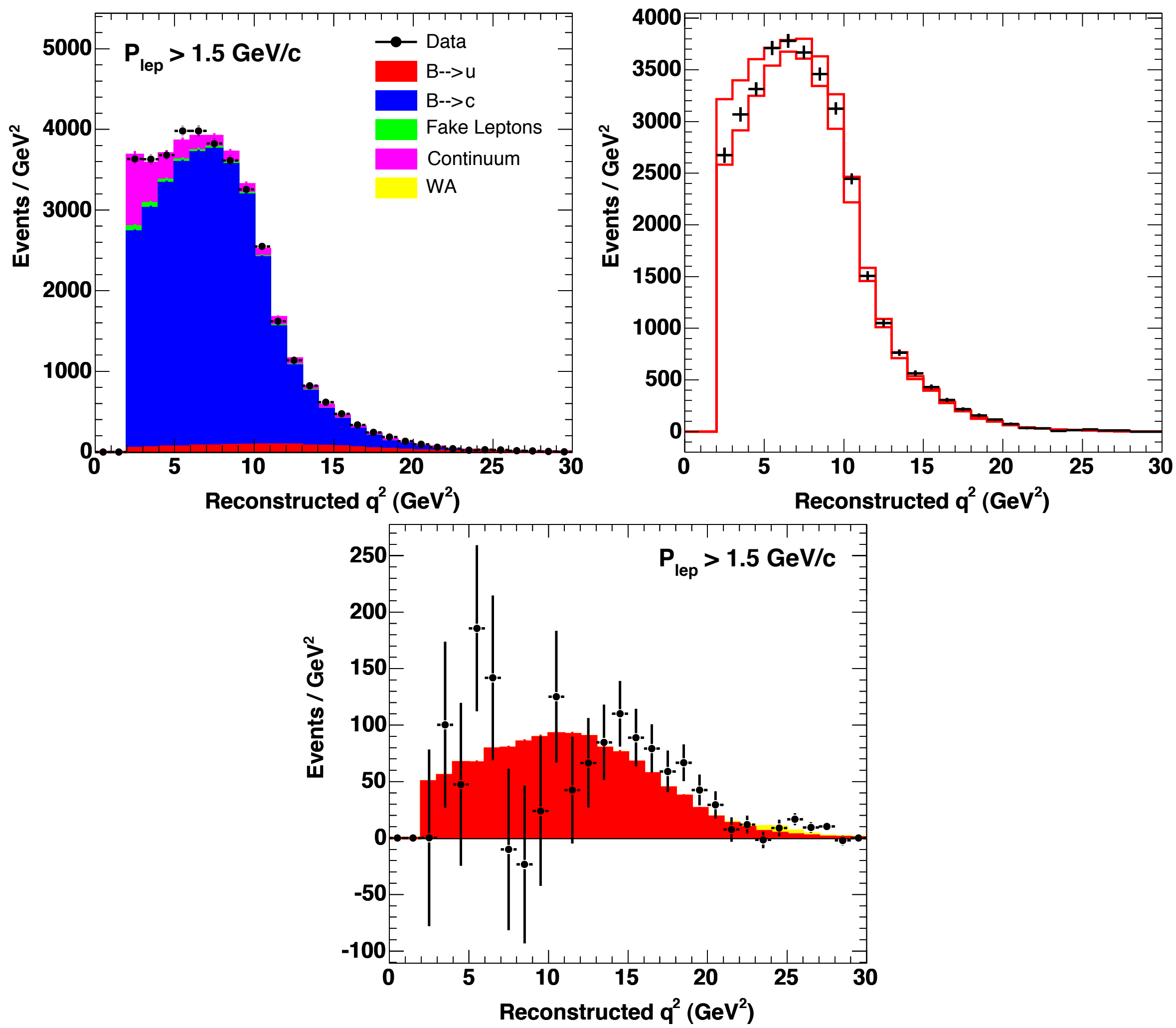

FIG. 2: The data q^2 distribution for $p_\ell > 1.5\,\text{GeV}/c$ compared to the fit results for the most localized WA model. Top left: Data (points) compared to all components (shaded histograms) for the nominal fit. Top right: continuum and fake lepton subtracted data (points) compared to the envelope of results from the systematic variations of the $B \to X_c \ell\nu$ modeling (histograms). Bottom: Background-subtracted data (points) for nominal fit with $B \to X_u \ell\nu$ (red histogram) and WA (yellow histogram) fit components.

drawing the mass M_X and momentum $|p_X|$ of the hadronic system independently from the pdf just described; these values uniquely determine the kinematics of the hadronic system, which is eventually hadronized into a system of $n \geq 2$ particles. The kinematics of the $\ell\nu$ pair are calculated assuming the $V - A$ structure of the weak current and spin $s = 0$ for the hadronic system. In this fashion, we create a Monte Carlo sample of B decays with kinematics consistent with our picture of weak annihilation. By choosing $5 \times 6 = 30$ different pairings of the parameters (x_0, Λ) in the sub-GeV range, we arrive at 30 different "realizations" of WA, or 30 different possibilities for how it might appear in our data. The plots in Fig. 1 illustrate some of the properties of these different samples, and emphasize the wide range of model space covered by our choice of parameter values.

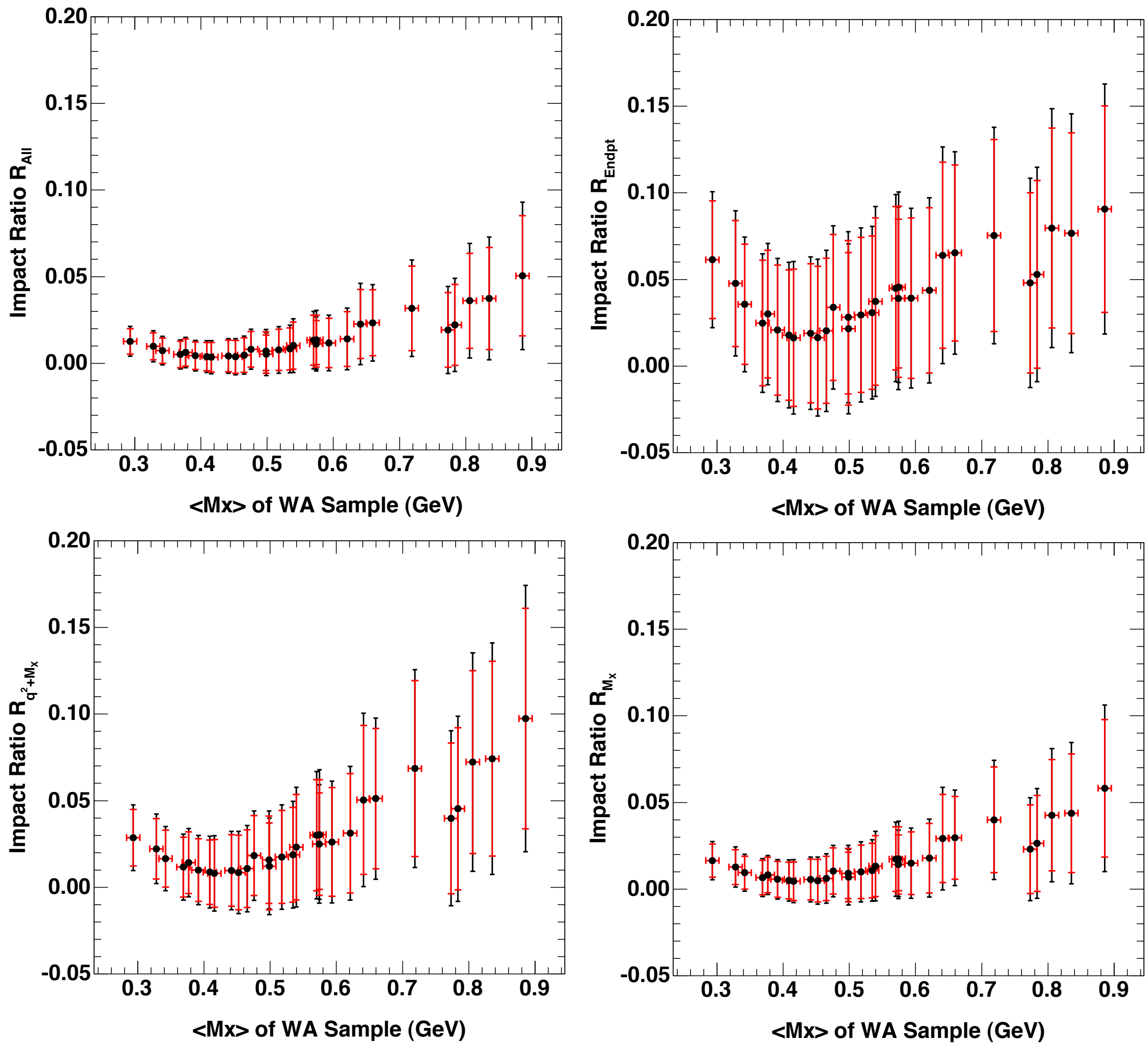

FIG. 3: Fractional size of WA for different hypothetical $b \to u$ analyses, computed from fit results for each WA sample. Statistical errors are shown in red; the total error including systematic uncertainties is shown in black. The top left plot shows the relative size of WA to the total $b \to u \ell \nu$ rate, with no cuts applied. The remaining plots show the impact of the WA effects when different sets of idealized cuts are applied at generator level, with the magnitude of WA as constrained by the fit to the data: "Endpt" ($|p_\ell| > 2.2$ GeV), "q^2 and M_X" ($|p_\ell| > 1.0$ GeV, $q^2 > 8.0$ GeV^2, $M_X < 1.7$ GeV), and "M_X" ($|p_\ell| > 1.0$ GeV, $M_X < 1.55$ GeV).

We perform separate χ^2 fits for each of our manifestations of WA, floating the background normalization, total $b \to u$ rate, and WA rate in each case. The continuum and fake lepton components are absolutely normalized based on sample luminosity. The result of the fit for the most concentrated WA model is shown in Fig. 2 integrated over the lepton momentum bins, that is, for $|\vec{p}_\ell| > 1.5\,\mathrm{GeV}/c$. A Kolmogorov-Smirnov test between the fit and observed data yields a probability of 0.91.

For each version of WA, we compute the fractional size of WA from the fit results, defining the ratio $R \equiv \Gamma_{\rm WA}/\Gamma_{b\to u}$; the denominator sums the contributions from our hybrid model of "traditional" $b \to u$ and the WA component identified by the fit. We plot the resulting constraint on the magnitude of WA parametrically in Fig. 3, against the mean hadronic mass of each WA sample computed at generator-level, and summarize the results in Table I. Statistical and systematic errors are included, including estimates of the sensitivity to the $b \to c$ background modeling and the hybrid component of the $b \to u$ signal.

We examine the relative importance of WA effects for different inclusive $b \to u$ analysis strategies by determining the fractional size of WA for a series of three different sets of hypothetical analysis cuts. Modified "impact" ratios are computed assuming "perfect" experimental cuts applied at generator level. These quantities essentially indicate the extent

TABLE I: Summary of "impact ratios" for the different WA models considered, indexed by the two model parameters x_0 and Λ (see text). The average hadronic mass $\langle M_X \rangle$ for each model is also presented. All units are in GeV.

x_0	Λ	$\langle M_X \rangle$	$R_{\rm tot}$ (%)	$R_{\rm endpt}$ (%)	$R_{q^2 M_x}$ (%)	R_{M_x} (%)
0.30	0.01	0.293	$1.27 \pm 0.74 \pm 0.45$	$6.14 \pm 3.39 \pm 1.98$	$2.86 \pm 1.64 \pm 0.96$	$1.64 \pm 0.95 \pm 0.56$
0.30	0.05	0.328	$0.73 \pm 0.73 \pm 0.38$	$3.56 \pm 3.47 \pm 1.77$	$1.66 \pm 1.64 \pm 0.84$	$0.95 \pm 0.94 \pm 0.48$
0.30	0.10	0.377	$0.44 \pm 0.80 \pm 0.37$	$2.08 \pm 3.76 \pm 1.70$	$0.99 \pm 1.81 \pm 0.83$	$0.57 \pm 1.04 \pm 0.47$
0.30	0.20	0.476	$0.42 \pm 0.91 \pm 0.42$	$1.90 \pm 4.01 \pm 1.82$	$0.97 \pm 2.06 \pm 0.94$	$0.55 \pm 1.18 \pm 0.54$
0.30	0.30	0.574	$0.77 \pm 1.19 \pm 0.62$	$2.95 \pm 4.47 \pm 2.29$	$1.75 \pm 2.68 \pm 1.38$	$1.00 \pm 1.54 \pm 0.80$
0.30	0.50	0.773	$0.98 \pm 0.78 \pm 0.46$	$4.77 \pm 3.63 \pm 2.08$	$2.22 \pm 1.74 \pm 1.00$	$1.27 \pm 1.00 \pm 0.58$
0.40	0.01	0.342	$0.51 \pm 0.76 \pm 0.36$	$2.48 \pm 3.62 \pm 1.68$	$1.16 \pm 1.72 \pm 0.80$	$0.66 \pm 0.99 \pm 0.46$
0.40	0.05	0.369	$0.35 \pm 0.86 \pm 0.42$	$1.63 \pm 3.96 \pm 1.92$	$0.80 \pm 1.96 \pm 0.95$	$0.45 \pm 1.12 \pm 0.54$
0.40	0.10	0.409	$0.47 \pm 0.99 \pm 0.48$	$2.03 \pm 4.19 \pm 2.01$	$1.08 \pm 2.24 \pm 1.08$	$0.61 \pm 1.28 \pm 0.62$
0.40	0.20	0.498	$1.02 \pm 1.36 \pm 0.75$	$3.73 \pm 4.83 \pm 2.59$	$2.31 \pm 3.04 \pm 1.64$	$1.32 \pm 1.76 \pm 0.95$
0.40	0.30	0.593	$0.63 \pm 0.79 \pm 0.38$	$3.00 \pm 3.68 \pm 1.76$	$1.42 \pm 1.78 \pm 0.85$	$0.81 \pm 1.02 \pm 0.49$
0.40	0.50	0.784	$0.38 \pm 0.82 \pm 0.41$	$1.79 \pm 3.76 \pm 1.86$	$0.87 \pm 1.86 \pm 0.92$	$0.50 \pm 1.06 \pm 0.53$
0.50	0.01	0.392	$0.37 \pm 0.95 \pm 0.44$	$1.64 \pm 4.12 \pm 1.88$	$0.85 \pm 2.16 \pm 0.99$	$0.49 \pm 1.23 \pm 0.57$
0.50	0.05	0.416	$0.53 \pm 1.10 \pm 0.55$	$2.15 \pm 4.41 \pm 2.16$	$1.21 \pm 2.50 \pm 1.23$	$0.69 \pm 1.43 \pm 0.71$
0.50	0.10	0.452	$1.33 \pm 1.44 \pm 0.83$	$4.50 \pm 4.72 \pm 2.63$	$3.01 \pm 3.21 \pm 1.79$	$1.73 \pm 1.87 \pm 1.05$
0.50	0.20	0.534	$0.80 \pm 1.03 \pm 0.53$	$3.38 \pm 4.21 \pm 2.11$	$1.83 \pm 2.31 \pm 1.16$	$1.04 \pm 1.33 \pm 0.67$
0.50	0.30	0.621	$0.70 \pm 1.12 \pm 0.57$	$2.81 \pm 4.42 \pm 2.21$	$1.58 \pm 2.52 \pm 1.26$	$0.90 \pm 1.45 \pm 0.73$
0.50	0.50	0.806	$0.83 \pm 1.22 \pm 0.65$	$3.08 \pm 4.42 \pm 2.30$	$1.88 \pm 2.73 \pm 1.42$	$1.07 \pm 1.57 \pm 0.82$
0.60	0.01	0.442	$1.35 \pm 1.43 \pm 0.92$	$4.56 \pm 4.67 \pm 2.91$	$3.04 \pm 3.17 \pm 1.98$	$1.75 \pm 1.84 \pm 1.16$
0.60	0.05	0.465	$2.27 \pm 1.99 \pm 1.23$	$6.39 \pm 5.37 \pm 3.20$	$5.04 \pm 4.30 \pm 2.56$	$2.92 \pm 2.54 \pm 1.52$
0.60	0.10	0.499	$1.12 \pm 1.34 \pm 0.79$	$3.91 \pm 4.56 \pm 2.63$	$2.50 \pm 2.96 \pm 1.71$	$1.43 \pm 1.71 \pm 0.99$
0.60	0.20	0.574	$1.17 \pm 1.42 \pm 0.74$	$3.92 \pm 4.63 \pm 2.34$	$2.62 \pm 3.13 \pm 1.59$	$1.50 \pm 1.81 \pm 0.92$
0.60	0.30	0.660	$1.40 \pm 1.58 \pm 0.82$	$4.37 \pm 4.77 \pm 2.40$	$3.12 \pm 3.45 \pm 1.74$	$1.79 \pm 2.00 \pm 1.01$
0.60	0.50	0.836	$2.34 \pm 1.90 \pm 1.12$	$6.53 \pm 5.08 \pm 2.88$	$5.12 \pm 4.05 \pm 2.29$	$2.96 \pm 2.39 \pm 1.36$
0.75	0.01	0.518	$3.17 \pm 2.44 \pm 1.33$	$7.54 \pm 5.54 \pm 2.88$	$6.85 \pm 5.08 \pm 2.62$	$4.00 \pm 3.05 \pm 1.59$
0.75	0.05	0.539	$1.93 \pm 2.15 \pm 1.30$	$4.81 \pm 5.20 \pm 3.08$	$3.98 \pm 4.35 \pm 2.57$	$2.30 \pm 2.55 \pm 1.52$
0.75	0.10	0.570	$2.21 \pm 2.34 \pm 1.33$	$5.29 \pm 5.42 \pm 2.98$	$4.53 \pm 4.68 \pm 2.57$	$2.63 \pm 2.77 \pm 1.53$
0.75	0.20	0.641	$3.61 \pm 2.74 \pm 1.86$	$7.97 \pm 5.78 \pm 3.76$	$7.23 \pm 5.28 \pm 3.44$	$4.26 \pm 3.22 \pm 2.11$
0.75	0.30	0.719	$3.74 \pm 2.94 \pm 1.97$	$7.67 \pm 5.79 \pm 3.74$	$7.43 \pm 5.62 \pm 3.61$	$4.38 \pm 3.42 \pm 2.22$
0.75	0.50	0.886	$5.05 \pm 3.47 \pm 2.47$	$9.06 \pm 5.96 \pm 4.07$	$9.74 \pm 6.36 \pm 4.31$	$5.82 \pm 3.96 \pm 2.71$

TABLE II: Summary of systematic contributions for the WA model with the most compact q^2 distribution.

	Change	
Systematic	Absolute	Fractional (%)
γ efficiency	0.0018	14
tracking efficiency	0.0023	18
E_γ resolution	0.0008	6
p_{trk} resolution	0.0011	9
K_L showering	0.0000	0
N_{K_L}	0.0001	1
hadronic shower modeling	0.0013	10
hadronic shower veto	0.0007	6
PID	0.0003	2
$b \to c \to s\ell\nu$	0.0002	1
Expt total	**0.0036**	**28**
$B \to X_c\ell\nu$ modeling	0.0022	18
$B \to X_u\ell\nu$ modeling	0.0016	13
Total	**0.0045**	**58**

to which a rate measured in a particular inclusive analysis can be biased away from current theoretical estimates because of a localized WA contribution, as constrained by our WA fit. The other plots in Fig. 3 illustrate these quantities in a fashion analogous to the main result. Note that while the hypothetical endpoint and hadronic mass analyses formally belong to the shape function regime, where the local OPE in which the WA operator is identified begins to break down, the combined q^2–M_X analysis steers clear of these complications. In each analysis scenario, our results, which are currently statistically limited, set non-trivial constraints on the possible contributions from bump-like WA effects.

The primary systematic uncertainties arise from experimental effects related to reconstruction of the neutrino, such as the absolute K_L and $b \to c \to s\ell\nu$ rates and spectra, the efficiency and resolution for charged particle and photon detection, modeling and rejection of charged hadronic showers, and charged hadron identification. Details of the variations can be found in reference [18]. The combined experimental systematics are about one half the statistical uncertainties, with small variations depending on the WA model and the region of phase space considered. Modeling of $B \to X_c\ell\nu$ is the next most important systematic, but about 1/2 the size of the experimental systematics. This systematic estimate includes variations of the branching fractions commensurate with recent measurements, and variation of form factors that are large (several standard deviations) compared to recent Heavy Flavor Averaging Group (HFAG) results [19]. Modeling of $B \to X_u\ell\nu$ contributes the final systematic at about one half the level of the $B \to X_c\ell\nu$ variations. The systematic studies include variations of the inclusive shape function similar to those from the CLEO $b \to s\gamma$ spectrum analysis for the lepton endpoint analysis [20], which are again conservative, and variations of the X_u hadronization model. Because we consider ratios of the WA component relative to the $B \to X_u\ell\nu$ component, many common systematics related to luminosity, fake rates, etc., largely cancel. The systematic contributions for the WA model with the most localized q^2 distribution are summarized in Table II.

Note that since these quantities reflect the relative size of WA in terms of rate, the fractional impact for extraction of $|V_{ub}|$ is half as large. The results indicate that a contribution to the $B \to X_u \ell \nu$ process that is concentrated at large q^2 introduces an uncertainty in an extracted $|V_{ub}|$ at the level of order 5% in analyses biased towards large q^2, and not at a more pessimistic $10-15\%$ (see, for example, reference [21]). These results are preliminary. We expect to fold in the $\sim$6 fb^{-1} of CLEO III $B\bar{B}$ data before publication of a combined analysis later this year.

We close by emphasizing that this analysis demonstrates the possibility of directly constraining the size of weak annihilation effects, albeit with an approach that can benefit from both further sophistication and the larger data samples available at the B factories (or in the charm sector). In particular, the approach described here is limited by the description of WA as a "bump" in the q^2 spectrum; the true effects may in fact be more subtle and much harder to sift from the data. Exploration of the moments of the q^2 distribution [22], for example, could provide a more model independent approach to limit the size of WA contributions that could be employed using the cleaner tagged samples at the B factories. In general, understanding weak annihilation and its effects on the extraction of $|V_{ub}|$ from semileptonic B decays will benefit from exploration along multiple avenues and across different experiments.

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. We thank Zoltan Ligeti and Michael Luke for their helpful discussions. This work was supported by the National Science Foundation and the U.S. Department of Energy.

[1] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[2] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **92**, 071802 (2004) [arXiv:hep-ex/0307062].

[3] I. Bizjak *et al.* [Belle Collaboration], arXiv:hep-ex/0505088.

[4] C. N. Burrell, M. E. Luke and A. R. Williamson, Phys. Rev. D **69**, 074015 (2004) [arXiv:hep-ph/0312366].

[5] S. W. Bosch, B. O. Lange, M. Neubert and G. Paz, Nucl. Phys. B **699**, 335 (2004) [arXiv:hep-ph/0402094].

[6] S. W. Bosch, M. Neubert and G. Paz, JHEP **0411**, 073 (2004) [arXiv:hep-ph/0409115].

[7] A. H. Hoang, Z. Ligeti and M. Luke, Phys. Rev. D **71**, 093007 (2005) [arXiv:hep-ph/0502134].

[8] B. O. Lange, M. Neubert and G. Paz, arXiv:hep-ph/0504071.

[9] I. I. Y. Bigi and N. G. Uraltsev, Nucl. Phys. B **423**, 33 (1994) [arXiv:hep-ph/9310285].

[10] M. Neubert and C. T. Sachrajda, Nucl. Phys. B **483**, 339 (1997) [arXiv:hep-ph/9603202].

[11] M. B. Voloshin, Phys. Lett. B **515**, 74 (2001) [arXiv:hep-ph/0106040].

[12] T. O. Meyer, Cornell University Ph.D. thesis, Jan 2005.

[13] Y. Kubota *et al.*, Nucl. Instrum. Meth. A **320**, 66 (1992).

[14] T. S. Hill, Nucl. Instrum. Meth. A **418**, 32 (1998).

[15] D. Cronin-Hennessy *et al.* [CLEO Collaboration], Phys. Rev. Lett. **87**, 251808 (2001) [arXiv:hep-ex/0108033].

[16] A. H. Mahmood *et al.* [CLEO Collaboration], Phys. Rev. D **67**, 072001 (2003) [arXiv:hep-ex/0212051].

[17] F. De Fazio and M. Neubert, JHEP **9906**, 017 (1999) [arXiv:hep-ph/9905351].

[18] S. B. Athar *et al.* [CLEO Collaboration], Phys. Rev. D **68**, 072003 (2003) [arXiv:hep-ex/0304019].

[19] J. Alexander *et al.* [Heavy Flavor Averaging Group (HFAG)], arXiv:hep-ex/0412073.

[20] A. Bornheim *et al.* [CLEO Collaboration], Phys. Rev. Lett. **88**, 231803 (2002) [arXiv:hep-ex/0202019].

[21] M. Battaglia and L. Gibbons, "Determination of $|V_{ub}|$", in *Review of particle physics*, S. Eidelman *et al.* [Particle Data Group], Phys. Lett. B **592**, 1 (2004).

[22] P. Gambino, G. Ossola and N. Uraltsev, arXiv:hep-ph/0505091.