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RECENT ARGUS RESULTS ON B MESON DECAYS

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ABSTRACT

Measurements of semileptonic B decays to D^{*-} and D^- mesons lead to consistent values for the Cabibbo-Kobayashi-Maskawa matrix element $|V_{cb}|$ of 0.046 ± 0.009 and 0.042 ± 0.008. A comparable result, $|V_{cb}| = 0.046\pm0.05$, is obtained from the study of the inclusive semileptonic decays. The lifetime ratio of B^+ and B^0 mesons is found to be $1.00 \pm 0.23 \pm 0.14$. A detailed study of the lepton momentum spectrum in $\Upsilon(4S)$ decays has been made. In the region from 2.3 to 2.6 GeV/c, which is above the endpoint for contributions from B decays via $b \to c$ transitions, 32 ± 10 events are observed in excess of known backgrounds. If these events are interpreted as a signal for $b \to u$ transitions, a model dependent value of 0.10 ± 0.02 for the ratio of CKM matrix elements $|V_{ub}|/|V_{cb}|$ is obtained. An update of the $B^0\overline{B}^0$ mixing measurement, with 70% more data, yields a value of the mixing parameter $r = 0.21 \pm 0.06$. Upper limits are obtained for many exclusive charmless B meson decays which can originate from $b \to u$ and $b \to s$ transitions.

Invited talk presented at the XIV International Symposium on Lepton and Photon Interactions, Stanford, August 7-12, 1989

1 Introduction

Of fundamental importance for our understanding of the weak interaction is a determination of the strength of the couplings between the third and first or second generation of quarks. The relationships among the quark-W boson couplings is expressed by the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix [1,2], with its four free parameters which have to be determined experimentally. Two of these elements are directly accessible through a study of B meson decays, namely V_{ub} and V_{cb}, which determine the strength of $b \to u$ and $b \to c$ transitions respectively. The latter process is known to dominate, as demonstrated by prolific charmed hadron production in B meson decays [3]. Searches for charmless decays, either in semileptonic or hadronic decay modes [3,4], have led to rather stringent limits on V_{ub}. Measurement of this coupling constant would greatly constrain our picture of weak-interaction physics. In particular, a non-zero value is essential for the Kobayashi-Maskawa explanation of the origin of CP violation [2].

The observation of an unexpectedly large $B^0\overline{B}^0$ mixing [5] demonstrated that V_{td} is nonzero. More precise measurements of the $B^0\overline{B}^0$ mixing rate can provide a stringent constraint on the free parameters of the CKM matrix. Finally, information about V_{ts} can be obtained from a study of loop induced $b \to s\gamma$ and $b \to s$ *gluon* transitions.

This review will summarize the recent ARGUS results relevant to the determination of the CKM matrix elements. Most of these were obtained using a data sample of about 170 pb^{-1} on the $\Upsilon(4S)$ and about 70 pb^{-1} in the nearby continuum at centre-of-mass energies below the open beauty threshold. There are about 150000 B meson pairs in this data sample.

2 The Transition $b \to c$

2.1 *The Decay* $B^0 \to D^{*-}\ell^+\nu$

A value for the V_{cb} matrix element can be extracted from measurements of the decay $B^0 \to D^{*-}\ell^+\nu$ provided its rich dynamics described by three substantial form factors is well understood (references in this paper to a specific charged state are to be interpreted as implying the charged-conjugate state as well). The decay $B^0 \to D^{*-}\ell^+\nu$ has been studied in detail by the ARGUS group [6,7]. B^0 mesons are produced almost at rest in $\Upsilon(4S)$ decays. Their energy coincides with the beam energy and their small momenta can be neglected. The decay $B^0 \to D^{*-}\ell^+\nu$ is therefore seen as a peak in the spectrum of recoil mass squared spectrum at $M^2_{rec} = 0$, where M^2_{rec} is given by

$$M^2_{rec} = [E_{Beam} - (E_{D^{*-}} + E_{\ell^+})]^2 - [\vec{p}_{D^{*-}} + \vec{p}_{\ell^+}]^2.$$

In order to calculate the branching ratio one must know a fraction of B^0 mesons in $\Upsilon(4S)$ decays. New CLEO measurements of the B^0 and B^+ meson masses show that the mass difference is very close to zero $M_{B^0} - M_{B^+} = 0.8 \pm 0.9\ MeV/c^2$ [8]. Therefore, it is reasonable to expect equal branching ratios for $\Upsilon(4S)$ decays into charged and neutral B mesons. Until a more definitive measurement is made, the ARGUS group will assume equal fractions of B^0 and B^+ mesons in $\Upsilon(4S)$ decays: $f_0/f_+ = 0.5/0.5$. This will change slightly the published values of B meson branching ratios because the previous assumption was $f_0/f_+ = 0.45/0.55$.

Scaling the published ARGUS result $BR(B^0 \to D^{*-}l^+\nu) = (7.0 \pm 1.2 \pm 1.9)\%$ [6] to the new value of $BR(D^{*-} \to \overline{D}^0\pi^-) = (57 \pm 4 \pm 4)\%$ [9], and assuming $f_0/f_+ = 0.5/0.5$, one obtains

$$BR(B^0 \to D^{*-}l^+\nu) = (5.4 \pm 0.9 \pm 1.3)\% \ .$$

This is the dominant semileptonic decay mode since the inclusive semileptonic branching ratio is about 10% (see chapter 2.4).

The average D^{*-} polarisation in this decay was studied using the strong two-body decay $D^{*-} \to \pi^-\overline{D}^0$ as a polarisation analyser by measuring the angle of the slow π^-, $\theta^*_{\pi^-}$, in the rest frame of the D^{*-} with respect to the D^{*-} boost direction. The distribution of $\theta^*_{\pi^-}$ can be parametrised as

$$N(\theta^*_{\pi^-}) \sim 1 + \alpha \cdot \cos^2\theta^*_{\pi^-} \ ,$$
$$\alpha = \frac{2\Gamma_L - \Gamma_T}{\Gamma_T} \ ,$$

where Γ_L and Γ_T are the longitudinal and transverse contributions to the decay width. The measured pion angular distribution is almost flat which corresponds to comparable values of Γ_L and Γ_T in this decay:

$$\Gamma_L/\Gamma_T = 0.85 \pm 0.45 \ .$$

The new CLEO measurements confirm the ARGUS results. The CLEO group obtained [10]:

$$BR(B^0 \to D^{*-}l^+\nu) = (4.6 \pm 0.5 \pm 0.7)\%$$

and

$$\Gamma_L/\Gamma_T = 0.83 \pm 0.33 \pm 0.13$$

for lepton momenta larger than 1.4 GeV/c.

All recent theoretical calculations [11,12,13] are in a good agreement with the experimental results. This gives some confidence in the values of V_{cb} extracted from the data although the results are still model dependent. A knowledge of Γ_L/Γ_T permits one to express $\Gamma(B^0 \to D^{*-}l^+\nu)$ independent of the theoretically most uncertain form factor [14]:

$$\Gamma(B^0 \to D^{*-}l^+\nu) = |V_{cb}|^2\tilde{\Gamma}^{(T)}(1 + \frac{\Gamma_L}{\Gamma_T}),$$

where $\tilde{\Gamma}^{(T)} = 1.2 \cdot 10^{13}\text{sec}^{-1}$ can be reliably calculated [14]. Inserting the measured numbers for the branching ratio and Γ_L/Γ_T and assuming that the B^0 lifetime is equal to the average

lifetime of beauty particles $\tau_B = (1.15 \pm 0.14)ps$ [3], one obtains:

$$|V_{cb}| \doteq 0.046 \pm 0.009 \ ,$$

where only experimental errors are included.

2.2 *The observation of the decay $B^0 \to D^-\ell^+\nu$*

Since the matrix element for reaction $B^0 \to D^-\ell^+\nu$ contains only one substantial form factor, a measurement of $BR(B^0 \to D^-\ell^+\nu)$ allows a nearly model independent determination of the CKM matrix element $|V_{cb}|$. However, it is more difficult to measure this decay because of a large combinatorial background and feed-down from the dominant decay $B^0 \to D^{*-}\ell^+\nu$ where $D^{*-} \to D^-\pi^0/\gamma$. Nevertheless, this channel was observed recently again using a missing mass technique [15]. The backgrounds were reduced considerably by requiring the D^- momentum to be larger than 1.5 GeV/c. Only 20% of D^- mesons from $B^0 \to D^-\ell^+\nu$ have momentum lower than 1.5 GeV/c, while the momentum spectrum of D^- mesons from the D^{*-} cascade decay $B^0 \to D^{*-}l^+\nu$ with $D^{*-} \to D^-\pi^0/\gamma$ is considerably softer [11]. Thus, the cut on the D^- momentum reduces the contribution from cascade decays, which is the main source of physical background. In addition this cut strongly reduces the combinatorial background.

Figure 1 shows the $K^+\pi^-\pi^-$ invariant mass spectra for events which contain a positive lepton in different intervals of M^2_{rec}. One observes a D^- peak at $M^2_{rec} \approx 0$ and no signal in the M^2_{rec} sidebands. The number of D^- mesons in each interval of M^2_{rec} was obtained from fits to these spectra.

Figure 2 shows the M^2_{rec} distribution for D^+l^- combinations after subtraction of the backgrounds from continuum, uncorrelated $D^-\ell^+$, and fake leptons. The prominent peak at $M^2_{rec} \approx 0$ includes the decay $B^0 \to D^-\ell^+\nu$ as well as a contribution from D^{*-} cascade decays. The latter has been determined from the data using D^{*-} decays to $\overline{D}^0\pi^-$. For $\overline{D}^0$ l^+ combinations the same kinematic cuts were applied as for D^- and l^+. After background subtraction 30 ± 7 $\overline{D}^0l^+$ candidates are retained.

A sum of two gaussians, representing the shapes of the direct and cascade decays, was fitted to the M^2_{rec} spectrum (Fig. 2). The contribution from D^{*-} cascade decays was constrained to lie within the errors of the measured number of $\overline{D}^0l^+$ combinations multiplied by the factor 2.3±0.5, which accounts for the relevant branching ratios [9,16] and efficiencies. By this procedure ARGUS obtains a signal of 82 ± 27 $B^0 \to D^-\ell^+\nu$ decays.

The dashed curve in Fig. 2 shows the fit result for the contribution (55 ± 18 events) from D^{*-} cascade decays. The contribution from other possible cascade decays has been tested by including the reflection from $\overline{D}_J(2420)^*$ in the fit. The fit result for this contribution is consistent with zero and does not change the number of $B^0 \to D^-\ell^+\nu$ decays.

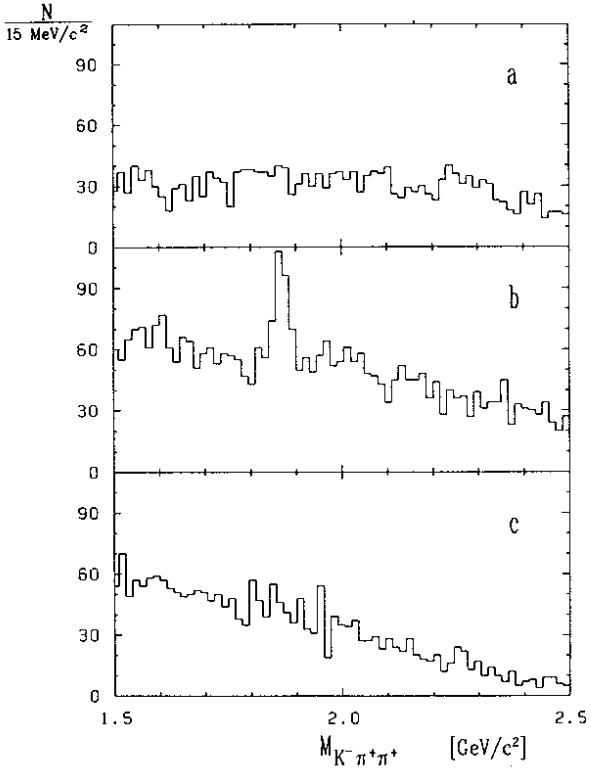

Figure 1: Invariant mass spectrum of $K^+\pi^-\pi^-$ combinations for different intervals of M^2_{rec} :
a) $-1.5 < M^2_{rec} < -0.5\ GeV^2/c^4$,
b) $-0.5 < M^2_{rec} < 0.5\ GeV^2/c^4$,
c) $0.5 < M^2_{rec} < 1.5\ GeV^2/c^4$.

Assuming $BR(\Upsilon(4S) \to B^0\overline{B^0}) = 50\%$ and electron-muon universality, ARGUS obtains

$$BR(B^0 \to D^-\ell^+\nu) = (1.7 \pm 0.6 \pm 0.4)\% .$$

Using this branching ratio, the WBS model [11], and $\tau_B = (1.15 \pm 0.14)ps$ [3] one obtains

$$|V_{cb}| = 0.042 \pm 0.008 .$$

Values for $|V_{cb}|$ obtained using other theoretical models [12,13,17,18,19] differ only by 10%. Thus the model dependence of the determination of $|V_{cb}|$ is considerably smaller than the experimental errors.

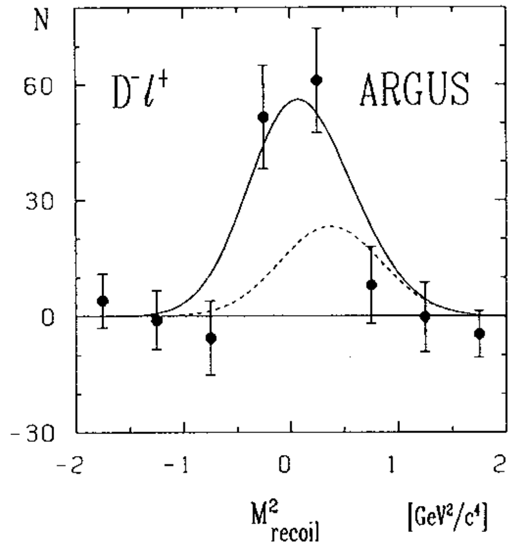

Figure 2: Distribution of M^2_{rec} against the D^-l^+ system. The dashed curve shows the contribution from the D^{*-} cascade decays.

The ratio of branching ratios for semileptonic B decays into the vector and pseudoscalar D mesons is close to the expectations from naive spin counting:

$$R = \frac{BR(B^0 \to D^{*-}l^+\nu)}{BR(B^0 \to D^-l^+\nu)} = 3.3 \pm {}^{3.7}_{1.1} ,$$

although the errors are still large. Model predictions for R vary from 1.2 to 9.6 [18,17].

2.3 *A Determination of* $\tau(B^+)/\tau(B^0)$

The lifetimes of B^+_u and B^0_d mesons have not yet been measured separately. Decay-in-flight measurements of the b hadron lifetime at PEP and PETRA only yield the average over an unknown mixture of b-flavoured hadrons. The difference in the lifetimes depends on the role of non-spectator processes in weak hadronic decays. In B decays these effects are assumed to be small. Hence, the lifetime ratio should be close to one [20], although some models predict higher values [21]. The B^+ and B^0 lifetimes enter into every evaluation of decay widths from measured branching ratios and thereby also into the determination of the CKM matrix elements. Currently, one has to assume the lifetimes to be equal. It is valuable to justify this experimentally. Previously, only weak bounds have been obtained from the single lepton and dilepton rates in $\Upsilon(4S)$ decays: $0.43 < \tau(B^+)/\tau(B^0) < 2.3$ at 90% C.L. [22].

Due to the absence of final state interactions, the partial widths of semileptonic B^+ and B^0 decays can be assumed to be equal. Therefore $\tau(B^+)/\tau(B^0)$ should be equal to the ratio of the B^+ and B^0 meson semileptonic branching fractions. This ratio can be extracted from a reconstruction of semileptonic B decays with a $\bar{D}^0$ or D^- meson detected in the final state, since B^+ decays mainly to $\overline{D}^0$ while B^0 decays mainly to D^-. Thus the charge of the D meson tags the charge of the parent B meson.

Decays into the lowest-lying charmed pseudoscalar and vector mesons dominate the total semileptonic decay rate. Therefore the production of excited charmed states in semileptonic decays can be neglected, with small corrections as discussed below. Since $\bar{D}^{*0}$ decays do not produce D^- mesons [9,23], all D^- mesons in semileptonic decays originate from B^0 decays, while semileptonic B^+ decays always yield $\bar{D}^0$ mesons. Thus only $\bar{D}^0$ mesons produced in the chain $B^0 \to D^{*-}\ell^+\nu$, $D^{*-} \to \bar{D}^0\pi^-$ have a wrong charge. The branching ratio for this decay has, however, been measured [6,10]. Taking this cross-talk into account, one has

$$\frac{f_+}{f_0}\frac{\tau(B^+)}{\tau(B^0)} = \frac{N(\bar{D}^0\ell^+) - r^* N(D^{*-}\ell^+)}{r^- N(D^-\ell^+) + r^* N(D^{*-}\ell^+)} , \tag{1}$$

where $N(\bar{D}^0\ell^+)$ $[N(D^-\ell^+)]$ denotes the observed number of $\bar{D}^0$ $[D^-]$ lepton pairs and $N(D^{*-}\ell^+)$ the number of D^{*-}- lepton combinations where the D^{*-} has been reconstructed in the decay channel $D^{*-} \to \bar{D}^0\pi^-$. The coefficients r^* and r^- account for the reconstruction efficiencies of $\bar{D}^0$ decays relative to D^{*-} and D^- decays, respectively.

After background subtraction, ARGUS obtains $325 \pm 28 \pm 9$, $183 \pm 37 \pm 12$ and $58 \pm 9 \pm 3$ events from the decays $B \to \bar{D}^0\ell^+X$, $B \to D^-\ell^+X$ and $B \to D^{*-}\ell^+X$ respectively. Inserting these numbers into (1), ARGUS obtains [24]

$$\frac{\tau(B^+)}{\tau(B^0)} = 1.00 \pm 0.23 \pm 0.14 . \tag{2}$$

Semileptonic B decays to excited charmed meson states would partially violate the B meson tagging with the D meson charge. However, this effect can be taken into account assuming isospin conservation. Denoting by R the righthand side of equation (1), one finds

$$\frac{f_+}{f_0}\frac{\tau(B^+)}{\tau(B^0)} = \frac{R - \frac{2}{3}\delta(R+1)}{1 - \frac{2}{3}\delta(R+1)} , \tag{3}$$

where δ is a relative contribution of the excited charm states to the inclusive semileptonic B meson decay width. Figure 3 shows $\tau(B^+)/\tau(B^0)$ as a function of R for various values of δ. As can be infered from Fig.3, the possible contribution from excited states does not change the value obtained for $\tau(B^+)/\tau(B^0)$ and increases its error only slightly.

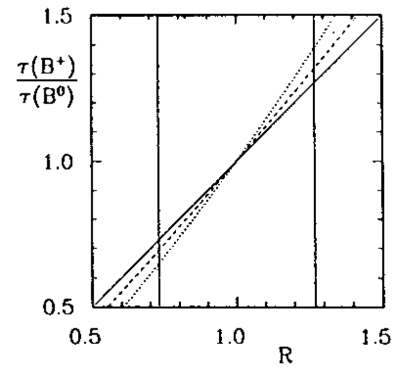

Figure 3: The lifetime ratio $\tau(B^+)/\tau(B^0)$ as a function of the measured ratio R for various contributions δ from decays $B \to \bar{D}_J^*\ell^+\nu$. Solid line: $\delta = 0$, dashed: $\delta = 0.1$, dotted: $\delta = 0.2$.

2.4 *The B Meson Semileptonic Branching Ratio*

The inclusive B meson semileptonic decay width depends on both V_{cb} and V_{ub}:
where the coefficients f_q are a product of a phase space factor and the lowest-order QCD correction. Since $|V_{ub}|$ is much smaller than $|V_{cb}|$ (see chapter 3.1-3.3) it can be neglected in this expression. Thus a value of $|V_{cb}|$ can be extracted from the measurements of the inclusive semileptonic branching ratio and the lifetime. Figure 4 shows the electron momentum spectrum on the $\Upsilon(4S)$ after continuum subtraction. The distribution is well described by contributions from $b \to cl^-\bar{\nu}$ transitions (dot-dashed curve) and secondary charm decays (dashed curve).

The electron and muon semileptonic branching ratios are obtained by fitting theoretical models to the experimental momentum distribution above 1.4 GeV/c where the contribution from the cascade decays is small. Using the ACM model [25] to extrapolate to the full spectrum ARGUS obtained [26]

$$BR(B \to \ell\nu X) = (10.3 \pm 0.7 \pm 0.2)\% ,$$

and

$$|V_{cb}| = 0.046 \pm 0.005 .$$

The CLEO and CUSB groups obtained similar branching ratios of $(10.1 \pm 0.3 \pm 0.7)\%$ and $(11.1 \pm 0.6)\%$ respectively [8]. The obtained value of $|V_{cb}|$ is in a good agreement with the results from the exclusive semileptonic decays although the sources of uncertainties in these approaches are very different. In the inclusive measurement, the main uncertainty is due to the very strong dependence of the semileptonic width on the not well known masses of b and c quarks. The agreement between the different methods of determining $|V_{cb}|$ provides some confidence that the model dependence of the obtained values is not too large.

However, it is worthwhile to mention that a somewhat larger value of $|V_{cb}| = 0.06 \pm 0.01$ was obtained using the parton model [27] for the analysis of the lepton spectrum measured by Crystal Ball [28]. The increase in $|V_{cb}|$ is only partially explained by the larger $BR(B \to \ell\nu X) = (12.0 \pm 0.5 \pm 0.7)\%$ obtained in this experiment.

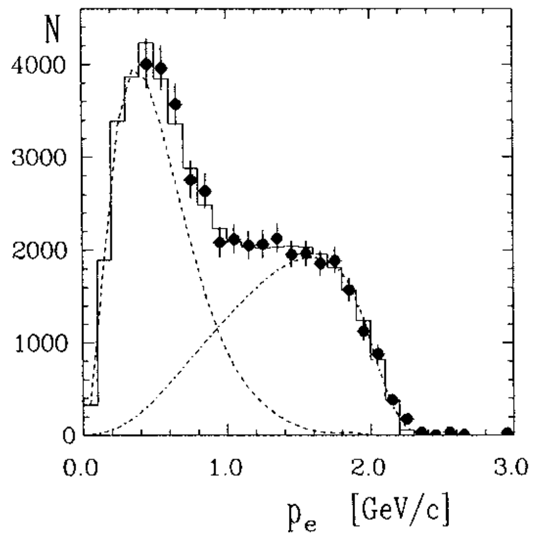

Figure 4: Electron spectrum at $\Upsilon(4S)$ after continuum subtraction.

The observed semileptonic branching ratio is smaller than the 12-15% predicted by the spectator model[29]. One possible explanation could be a substantial contribution from semileptonic decays into baryon antibaryon pairs such as $B \to \Lambda_c \overline{N} \ell\nu$. Leptons in these decays are soft because of the large baryon masses and would not influence a fit restricted to the high momentum range. No evidence for semileptonic B decays with antiprotons in the final state was found by ARGUS leading to the 90% CL upper limit $BR(B \to \bar{p} e^{\pm} X) < 0.36\%$. Protons from hyperon decays are included into this limit. The neutron yield is not expected

to be larger than the proton yield. Therefore semileptonic B decays to baryons can not explain the difference between experiment and theory.

3 The $b \to u$ Transition

3.1 *A Study of the Lepton Spectrum Near the Endpoint*

The signature for a decay via a $b \to u$ transition would be seen as an excess of leptons with momenta above the kinematic limit of about 2.3 GeV/c for $b \to c$ decays. And there is some excess in the $\Upsilon(4S)$ data over the scaled continuum in the momentum interval from 2.3 to 2.6 GeV/c (see Fig.5).

The spectra in Fig.5 were obtained selecting events with no particles above the kinematic limit for B decays (except identified leptons) and with not too small charged $n_{ch} > 4$ and total $n_{ch} + n_{\gamma}/2 > 5$ multiplicity.

The polar angle of electrons was restricted to the region $|cos\theta_e| < 0.85$ to ensure a good momentum resolution. Muons were used only in the barrel region where the fake rate is twice smaller.

After bin-by-bin subtraction of the continuum, 73 ± 39 electrons and 131 ± 53 muons are left in the interval 2.3 to 2.6 GeV/c. The errors include the uncertainties in the continuum scaling factors for electrons and muons, which were taken to be the ratio of the number of leptons detected on the $\Upsilon(4S)$ and in the continuum, above the kinematic limit for B decays.

There are a number of backgrounds from $\Upsilon(4S)$ events themselves. Perhaps the most critical of these is the high momentum tail of the contribution from $b \to c$ decays. This depends on the experimental resolution function and on the model used for the semileptonic $b \to c$ decays.

The resolution function for muons has been checked by studying QED μ-pair events. The muon momentum distribution has practically no high energy tail and it is perfectly described by the detector Monte Carlo. The extrapolation to the lower momenta of the $b \to u$ analysis should be quite reliable, since this is still a regime where drift chamber resolution dominates the precision of the momentum determination. The same holds true for estimates of the electron response function which was studied using Bhabha events. Using the available models for $b \to c$ decays [11,12,13], and varying the D/D^* ratio within experimental limits, the uncertainty in the background from $b \to c$ decays in the signal region is estimated to be 25%.

After subtracting continuum and backgrounds from $b \to c$ transitions, fake leptons and J/ψ decays, the number of signal events was found to be 39 ± 40 and 81 ± 54 for electrons and muons respectively. In the normalization region from 2.0 to 2.3 GeV/c, populated mainly by $b \to c$ transitions, the corresponding numbers were 864 and 852 events.

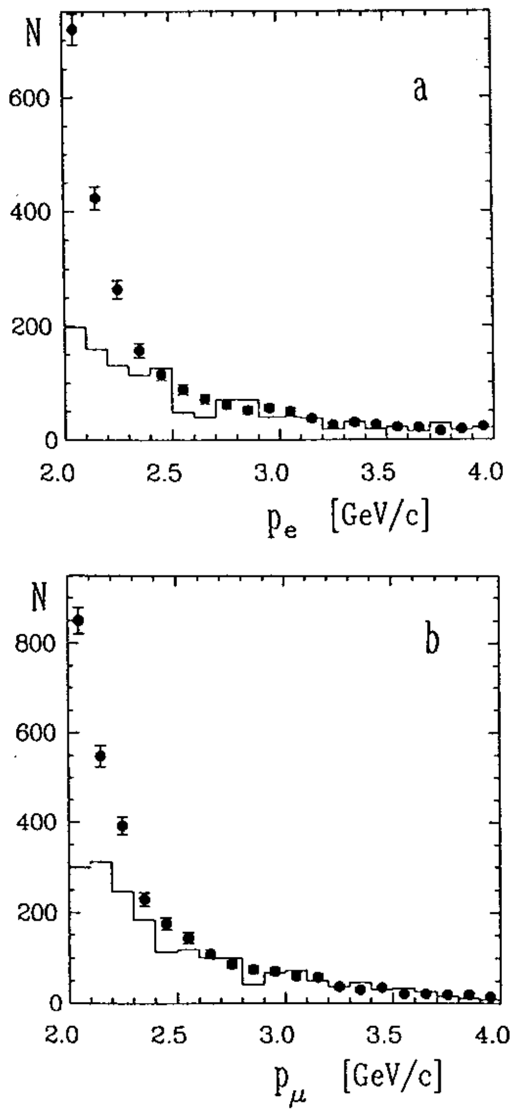

Figure 5: Momentum spectra for (a) electrons and (b) muons from $\Upsilon(4S)$ (points) and scaled continuum (histogram) data.

Clearly the sensitivity of the inclusive approach is limited by the subtraction of a large

amount of continuum, using a scaling factor which by itself has large uncertainties. In proceeding further, the approach has been to use additional requirements which strongly suppress the continuum, but which have a reasonable efficiency for $b \to u$ decays. These requirements exploit the more spherical shape of $\Upsilon(4S)$ decays in comparison with continuum events and the existence of energetic leptons (including neutrinos) in B meson decays. The data were divided into two independent samples: one consisting of those events containing exactly one lepton and the other containing those events with exactly two. The requirement of an additional fast lepton ($1.2 < p_l < 2.3$ GeV/c) already suppresses strongly the continuum contribution in the second sample. In the single lepton sample the continuum contribution was reduced by requiring a nonjet topology of the events. Finally, the presence of an energetic neutrino which manifests itself as a large missing momentum was required in both samples.

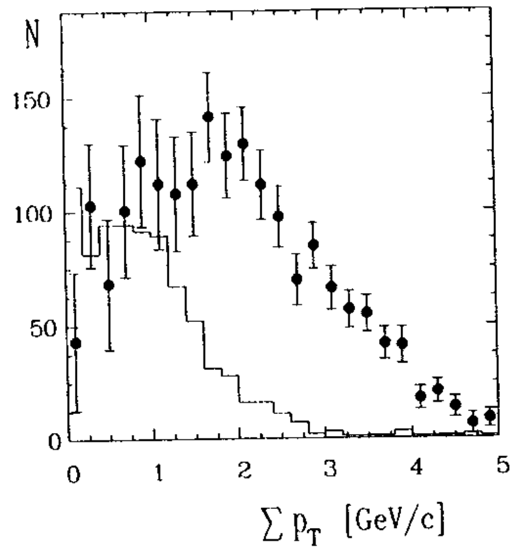

Figure 6: Distribution of $\sum p_T$ for continuum (histogram) and $\Upsilon(4S)$(points) events, for lepton momentum in the range 2.0 to 2.3 GeV/c.

Events with a two-jet topology in the single lepton sample were removed by a requirement of a large transverse energy with respect to the lepton. Fig.6 shows the scalar sum of transverse momenta with respect to the lepton ($\sum p_T$) of all particles which have an angle with the lepton between 60° and 120°. There is an obvious difference between the $\Upsilon(4S)$ and continuum data. The requirement that $\sum p_T$ exceed 2 GeV/c reduces the continuum by a factor of 13, while its efficiency for $\Upsilon(4S)$ decays with $2 < p_\ell < 2.3 GeV/c$ is still 46%. The efficiency for the $b \to u$ transitions with $2.3 < p_\ell < 2.6 GeV/c$ was estimated using the WBS model [11] to be 41%.

Semileptonic decays produce a neutrino along with the charged lepton, resulting in missing momentum (p_{miss}) for the event. As noted previously, many of the continuum leptons, particularly in the muon sample, are misidentified hadrons, and so these events should have small missing momentum. A requirement of large p_{miss} also suppresses purely hadronic decays of the $\Upsilon(4S)$. This is of particular importance for reducing backgrounds from $B \to J/\psi X$, for example.

For semileptonic decays the direction of the neutrino ($\mathbf{p}_{miss}$) and the lepton momentum are strongly correlated, particularly for leptons in the endpoint region. The opening angle, $\cos\beta$, between the lepton direction and the direction of missing momentum should peak at $\cos\beta = -1$ for signal events. The actual strength of the correlation depends on the quality of the detector, since the resolution for $\cos\beta$ is a function of the hermiticity of the experiment.

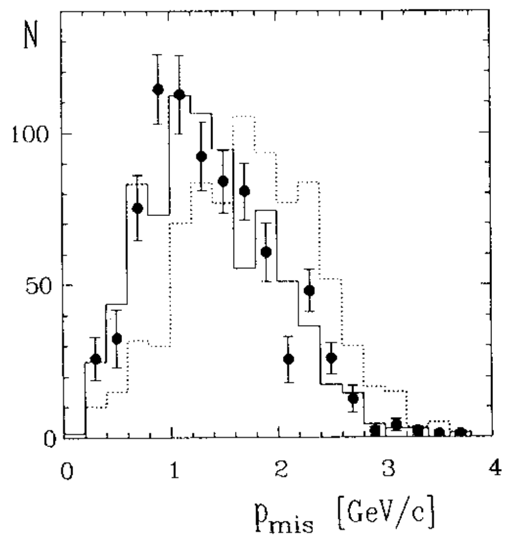

Figure 7: Distribution of p_{miss} for $\Upsilon(4S)$ data with leptons in the $b \to c$ range (circles), Monte Carlo prediction for $b \to c$ (open histogram) and $b \to u$ (dotted histogram) transitions.

Shown in Figure 7 and 8 are comparisons between Monte Carlo predictions and direct $\Upsilon(4S)$ decays for the distribution of p_{miss} and $\cos\beta$ in the region $2.0 < p_\ell < 2.3$ GeV/c populated mainly by $b \to c$ decays. Both the magnitude and angular correlation with $\mathbf{p}_{miss}$ are well described by the Monte Carlo. For comparison, the predicted p_{miss} and $\cos\beta$ distributions

for $b \to u$ transitions are also shown. These were obtained by Monte Carlo calculation using the WBS model [11] for semileptonic B decays to π and ρ mesons.

In order to further demonstrate that the observed peaking of $\cos\beta$ near -1 is due to the neutrino and not an artifact, the opening angle between the known neutrino direction and $\mathbf{p}_{miss}$ for the exclusive sample of $B^0 \to D^{*-}\ell^+\nu$ was examined.

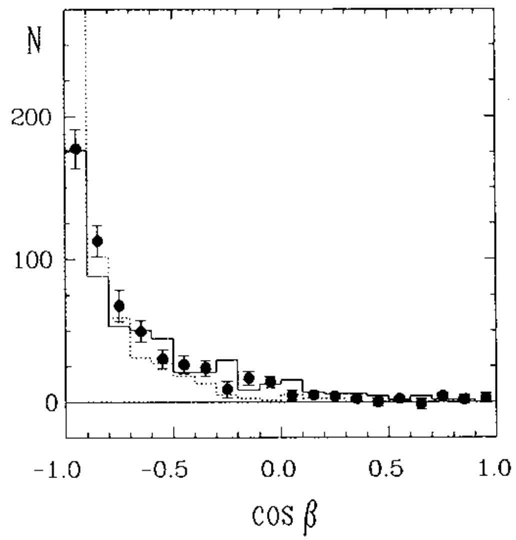

Figure 8: Distribution of $\cos\beta$. Notations as in Fig.7.

The result is shown in Figure 9, where $\mathbf{p}_{miss}$ can be seen to coincide with $\mathbf{p}_\nu$ with approximately the same precision as seen in Figure 8.

For the single-lepton analysis, the requirement was made that $1.0 < p_{miss} < 3.5$ GeV/c and $\cos\beta < -0.5$. The efficiency of the cut has been estimated to be 81% for $b \to u$ decays, while at the same time the background is reduced by a factor of 3.

In total, the requirements discussed above on $\sum p_T$ and $\mathbf{p}_{miss}$ reduce the continuum contribution by the factor of more than 40 while keeping a reasonably high efficiency for a $b \to u$ signal of 0.33.

Finally, the contribution from J/Ψ decays was further suppressed by requiring the invariant mass of the lepton with any other oppositely charged track consistent with the lepton hypothesis be more than 100 MeV/c^2 away from the J/Ψ mass.

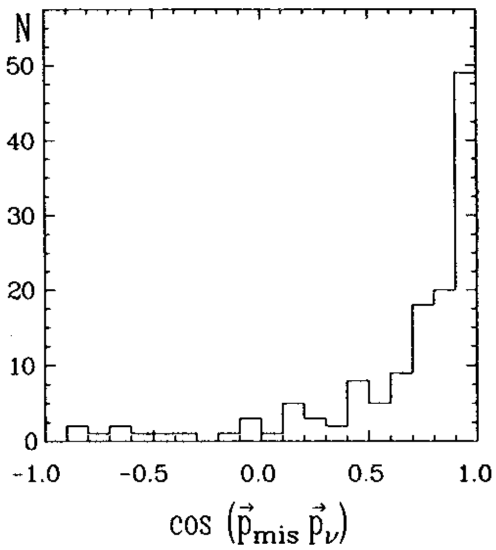

Figure 9: Opening angle distribution between $\mathbf{p}_{miss}$ and the known neutrino direction for $B^0 \to D^{*-}\ell^+\nu$ events.

The momentum distributions for electrons and muons after application of these cuts are shown in Figure 10 for both $\Upsilon(4S)$ and continuum data. The continuum background can be seen to have been dramatically reduced. In the signal region for $b \to u$ decays, 40 leptons are observed with the estimated background of 18.4±6.5 events. Table 1 gives a detailed description of the background sources. Thus, there is an excess of 22 ± 9 leptons in the momentum region $2.3 < p_\ell < 2.6$ GeV/c. The normalization region for $b \to c$ decays was taken, as before, to be the interval $2.0 < p_\ell < 2.3$ GeV/c, where 206 electron and 201 muon candidates are observed after background subtraction.

In the dilepton sample the small continuum contamination was further suppressed by requiring that the opening angle, $\theta_{\ell^+\ell^-}$, between the two leptons satisfy the requirement $\cos\theta_{\ell^+\ell^-} > -0.8$. Converted photons were removed by the restriction that $\cos\theta_{\ell^+\ell^-}$ be less than 0.95 for electron pairs. The J/ψ decays were removed as in the first sample. Finally, the missing momentum in the event was again required to lie in the interval $1.0 < p_{miss} <$ 3.5 GeV/c.

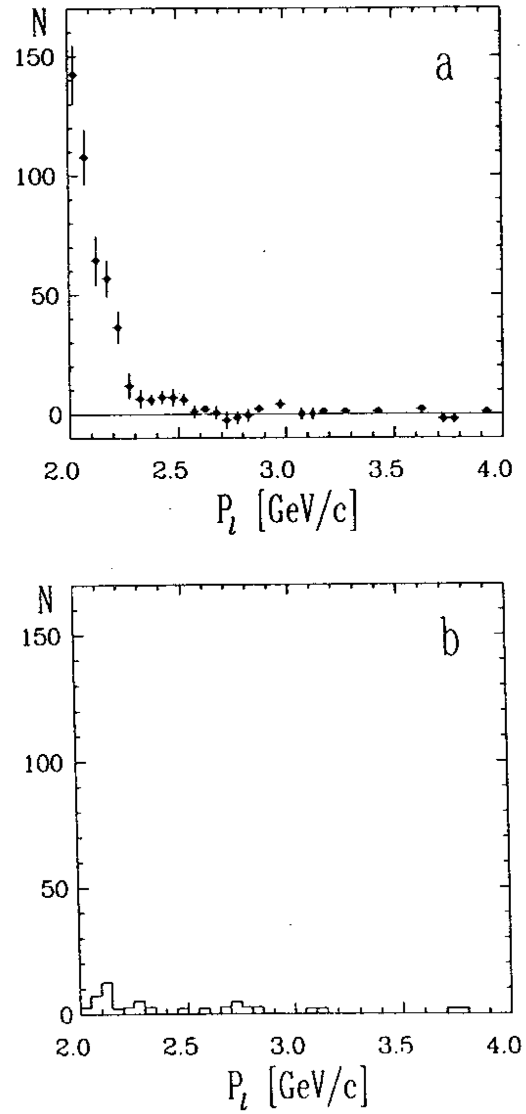

Figure 10: Lepton momentum spectra for (a) $\Upsilon(4S)$ data after continuum subtraction and (b) scaled continuum.

The resulting momentum spectrum is shown in Figure 11, where the four events observed in the continuum are indicated by the histogram. There is no continuum event in the $b \to u$ signal region. However, we subtract the average level of continuum in the 2 to 3 GeV/c range. The $b \to u$ momentum interval is populated in the $\Upsilon(4S)$ data by 15 events, with an estimated background of 5.8 ± 1.6. There are 6 $e\mu$, 4 ee and 5 $\mu\mu$ candidates, a reasonable division of the signal.

Table 1 gives a detailed breakdown of the known background sources. After background subtraction there are 59 electrons and 59 muons in the 2.0 to 2.3 GeV/c range.

Table 1. Observed single lepton and dilepton events in the momentum interval $2.3 < p_\ell < 2.6$ GeV/c and estimated backgrounds.

	Single Leptons		Dileptons	
	e	μ	e	μ
$\Upsilon(4S)$	24	16	7	8
Continuum	4.2	2.6	0.7	0.7
$b \to c$	4.1	4.6	1.2	1.3
J/ψ	0.5	0.3	0.2	0.1
Fakes	0.7	1.4	0.5	1.1
Sum	9.5 $\pm$4.4	8.9 $\pm$4.8	2.6 $\pm$0.8	3.2 $\pm$0.9
Signal	14.5 $\pm$6.6	7.1 $\pm$6.2	4.4 $\pm$2.8	4.8 $\pm$3.0

Figure 12 shows the combined lepton spectrum for both single and double lepton samples. Altogether there are 55 leptons between 2.3 and 2.6 GeV/c with the background estimated to be only 23 ± 7 events. The uncertainty of the background is dominated by the Poisson error on the continuum contribution. There are a total of 3 continuum events and the average continuum scaling factor is 2.35. Therefore the statistical significance of the signal corresponds to 3.3 standard deviations. In the momentum interval 2.4 to 2.6 GeV/c, where the $b \to c$ background vanishes completely, 32 leptons remain with an estimated background of 7.2 ± 7.

Assuming that $\Upsilon(4S)$ decays only to $B\overline{B}$ pairs, ARGUS interprets the observed excess of leptons beyond the endpoint for $b \to c$ decays as a signal for $b \to u$ transitions. Taking into account that the efficiency for $b \to u$ transitions is 1.3 times larger than the efficiency

for $b \to c$ transitions with $2.0 < p_\ell < 2.3$ GeV/c, one obtains

$$\frac{BR_{sl}(2.3-2.6)}{BR_{sl}(2.0-2.3)} = 4.5 \pm 1.4\% .$$

The errors do not include the uncertainty due to the model dependence of the efficiency calculations for $b \to u$ transitions. Main uncertainty comes from the requirements on $\mathbf{p}_{miss}$. However this uncertainty can not lead to a substantial decrease of the obtained ratio of branching ratios since the used estimation of the corresponding efficiency is close to one (81%).

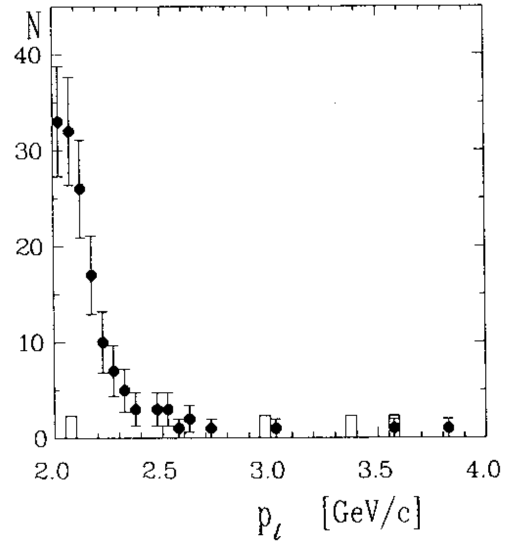

Figure 11: Momentum spectra in dilepton sample for $\Upsilon(4S)$ (points) and scaled continuum (histogram) data.

In order to calculate $|V_{ub}|/|V_{cb}|$ one must know the fractions of lepton spectra for $b \to u$ and $b \to c$ transitions in the selected momentum intervals. These fractions are different for electrons and muons because of electron bremsstrahlung. They are also model dependent, because of the very large theoretical uncertainties in the predictions for semileptonic B decays via $b \to u$ transitions. Using the ACM model [25] and neglecting the $b \to u$ contribution below 2.3 GeV/c one obtains a model dependent result

$$|V_{ub}|/|V_{cb}| = 0.10 \pm 0.02 .$$

It should be stressed that the errors for $|V_{ub}|/|V_{cb}|$ are not Gaussian and the statistical significance of the signal is 3.3 standard deviations.

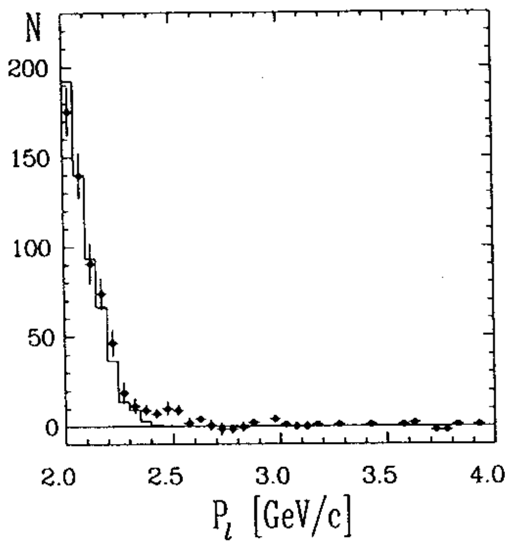

Figure 12: Combined lepton spectrum after continuum subtraction; histogram is a $b \to c$ contribution normalized in the region 2.0 to 2.3 GeV/c.

3.2 *A Search for Exclusive Charmless Decays*

A search for exclusive decays $B^+ \to \rho^0 \ell^+ \nu$ and $B^0 \to \pi^- \ell^+ \nu$ was performed for leptons with $1.5 < p_\ell < 2.7 GeV/c$ [31] using the usual missing mass technique. No signal was observed. However, the background level is high and limits are model dependent and not very restrictive. The highest upper limit comes from the GISW model [13]:

$$|V_{ub}|/|V_{cb}| < 0.3 \ .$$

In 1987 ARGUS observed a signal of 25 ± 8 events in the decays $B \to p\bar{p}\pi^+(\pi^-)$ [32]. The CLEO group, however, does not see a corresponding excess in the B mass region [33,4]. A preliminary analysis of new ARGUS data, corresponding to 70% of the previous sample, also do not show the expected signal. New data, which ARGUS is taking in 1989, will help to clarify the situation.

Theory predicts quite substantial branching ratios for B decays to multipion final states [34]. ARGUS performed a search for such decays with up to 6 pions. No signals were observed. The obtained upper limits are summarized in Table 2 together with the theoretical predictions [34] and CLEO results [4]. The backgrounds in channels with large expected branching ratios are also large and the upper limits are still much higher than the theoretical predictions for

$|V_{ub}|/|V_{cb}|$=0.1.

Table 2. Limits on charmless B decays

Decay	ARGUS 90%CL	CLEO 90%CL	Theory $\|V_{bu}/V_{bc}\|$=0.1
$\pi^\pm\pi^0$	$5.0 \cdot 10^{-4}$	$2.6 \cdot 10^{-3}$	$0.6 \cdot 10^{-5}$
$\pi^+\pi^-$	$1.9 \cdot 10^{-4}$	$0.8 \cdot 10^{-4}$	$2.0 \cdot 10^{-5}$
$\pi^\pm\pi^+\pi^-$	$8.0 \cdot 10^{-4}$	$1.9 \cdot 10^{-4}$	$6 \cdot 10^{-5}$
$\rho^0\pi^\pm$	$1.9 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$	$2 \cdot 10^{-6}$
$\pi^+\pi^-\pi^0$	$1.8 \cdot 10^{-3}$	–	$2 \cdot 10^{-4}$
$\rho^0\pi^0$	$4.3 \cdot 10^{-4}$	–	$2 \cdot 10^{-6}$
$\pi^+\pi^+\pi^-\pi^-$	$1.0 \cdot 10^{-3}$	–	$1 \cdot 10^{-4}$
$\pi^\pm\pi^+\pi^-\pi^0$	$5.4 \cdot 10^{-3}$	–	$4 \cdot 10^{-4}$
$\pi^+\pi^-\pi^0\pi^0$	$5.7 \cdot 10^{-3}$	–	$5 \cdot 10^{-4}$
$\rho^+\rho^-$	$4.2 \cdot 10^{-3}$	–	$5 \cdot 10^{-5}$
$\pi^\pm 2\pi^+ 2\pi^-$	$1.2 \cdot 10^{-3}$	–	$2 \cdot 10^{-4}$
$3\pi^+3\pi^-$	$3.3 \cdot 10^{-3}$	–	$2 \cdot 10^{-4}$

4 Update on $B^0\overline{B}^0$ Mixing

Large $B^0\overline{B}^0$ mixing is well established [5][35]. In this section an update on the $B^0\overline{B}^0$ mixing study [5] is presented with the 70% more data collected in 1988 (altogether $172pb^{-1}$ on the $\Upsilon(4S)$ and $55pb^{-1}$ in continuum).

The mass difference ΔM between the CP eigenstates in the B system is given by [36]

$$\Delta M = \frac{G_F^2}{6\pi^2} B_B f_B^2 m_b \, |V_{tb}^* V_{td}|^2 \, m_t^2 F(\frac{m_t^2}{M_W^2}) \eta_{QCD} \ .$$

All parameters in this expression, except of V_{td} and m_t, are either known or can be calculated (although the accuracy in $B_B f_B^2$ is poor). Thus the knowledge of ΔM constrains the product of V_{td} and m_t. ΔM can be obtained from the measurements of the experimentally accessible mixing parameter r which is connected to ΔM by

$$r = \frac{Prob(B^0 \to \overline{B}^0)}{Prob(B^0 \to B^0)} = \frac{(\Delta M \cdot \tau_b)^2}{2 + (\Delta M \cdot \tau_b)^2} \ .$$

The most accurate method for measuring the mixing rate is by tagging B^0 and $\overline{B}^0$ mesons with the charge of the lepton from the semileptonic decays. B^0 mesons decay only to ℓ^+

while $\overline{B}^0$ produce only ℓ^-. Thus $B^0\overline{B}^0$ mixing should lead to like-sign lepton pairs. Using cuts similar to those in the previous study [5] ARGUS observes 70 like-sign and 403 unlike-sign lepton pairs. After background subtraction a mixing signal of 34.7 like-sign lepton pairs is observed as well as 381.4 unlike-sign leptons from $B^0, \overline{B}^0$ and B^+, B^- decays. Table 3 gives a detailed breakdown of the background sources.

Table 3. Dilepton rates

	$N(\ell^\pm\ell^\pm)$	$N(\ell^+\ell^-)$
$\Upsilon(4S)$ + Continuum	70	403
Continuum	2	7
$\Upsilon(4S)$ direct	64.2	382.4
Corrected for J/ψ cut	64.2	413.6
	±10.2	±23.3
Background		
Fakes	12.5	23.8
Conversion	0.6	0.6
Secondary decays	14.7	6.1
J/ψ decays	1.7	1.7
Signal	34.7	381.4
	±10.2	±23.3

For $\Upsilon(4S)$ decays the mixing parameter r is given by:

$$r = \frac{N_{\ell^\pm\ell^\pm}(1+\lambda)}{N_{\ell^+\ell^-} - N_{\ell^\pm\ell^\pm}\cdot\lambda}$$

where the parameter

$$\lambda = \frac{f^+}{f^0}(\frac{\tau_{B^+}}{\tau_{B^0}})^2$$

accounts for unlike-sign dileptons which come from $\Upsilon(4S) \to B^+B^-$ decays. As discussed above (see chapters 2.1, 2.3), one expects $f_+/f_0 \approx 1$ and $\tau_{B^+}/\tau_{B^0} \approx 1$.Therefore $\lambda = 1$ is assumed for the determination of r (previously $\lambda = 1.2$ was assumed by ARGUS [5] and CLEO [35]). Using $\lambda = 1$ one obtains:

$$r = 0.20 \pm 0.06 \pm 0.05 \,,$$

where the systematic error accounts for the uncertainties in the background estimates.

A second method is to reconstruct one B^0 meson using the decay $B^0 \to D^{*-}\ell^+\nu$ while the second B is tagged again with the lepton charge. Table 4 gives the observed number of

events and background estimates. Using these numbers one finds:

$$r = \frac{N(D^{*+}\ell^-\ell^-)}{N(D^{*+}\ell^-\ell^+)} = 0.24 \pm 0.12 \,.$$

Since one B^0 meson is reconstructed the result does not depend on λ.

Table 4. Dilepton events with D^{*+} mesons

	$N(D^{*+}\ell^-\ell^-)$	$N(D^{*+}\ell^-\ell^+)$
At Υ(4S)	8	27
Background	1.9 ± 0.5	1.7 ± 0.5
Signal	6.1 ± 2.8	25.3 ± 5.9

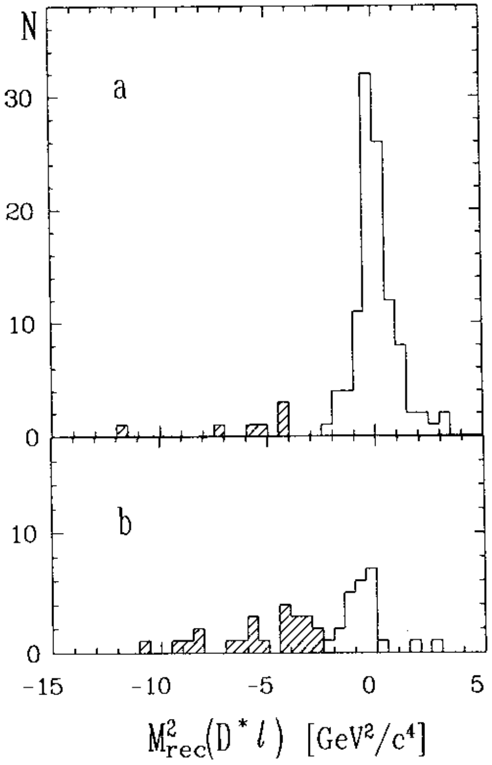

Figure 13: M^2_{rec} distribution for (a) $D^{*-}\ell^+$ and (b) $D^{*-}\ell^-$ combinations.

A third independent method, assumes that D^{*+} mesons are only produced in the decay of $\overline{B}^0$ mesons and thus can serve as a tag. The other B^0 or $\overline{B}^0$ meson is again tagged with the charge of the lepton. A requirement that $M^2_{rec} < -2.5GeV^2/c^4$ ensures that the D^{*+} and the $\ell^{\pm}$ come from different B mesons. The obtained M^2_{rec} spectra are shown in Fig.13 and the numbers are given in Table 5.

Table 5. $D^{*+}\ell^{\pm}$ events

	$N(D^{*+}\ell^-)$	$N(D^{*+}\ell^+)$
At $\Upsilon(4S)$	7	23
Background	2.0 ± 0.5	2.3 ± 0.5
Signal	5.0 ± 3.1	20.7 ± 5.5

For the mixing parameter r, ARGUS obtains, under the above assumption,

$$r = \frac{N_{D^{*+}\ell^-}}{N_{D^{*+}\ell^+}} = 0.24 \pm 0.16$$

This result is, within large errors, close to the results obtained by the other methods, indicating that indeed most of the D^{*+} mesons are decay products of $\overline{B}^0$ mesons. Possible decays of charged B mesons into D^{*+} mesons would increase the value for r obtained with this method.

Combining all results on r ARGUS finds

$$r = 0.21 \pm 0.06$$

in perfect agreement with the original observation.

Using this result together with the estimate $B_B^{\frac{1}{2}} f_B = (140 \pm 40) MeV$ [37], $m_t > 78 GeV/c^2$ from direct searches [38] and $m_t < 190 GeV/c^2$ from the analysis of electroweak radiative corrections to M_W/M_Z [40], one obtains

$$0.007 \leq | V_{td} | < 0.04 \ .$$

The upper limit is less restrictive than the limit $|V_{td}| < 0.018$ infered by invoking unitarity of the CKM matrix [39], but it does not depend on the model dependent upper limit on $|V_{ub}|/|V_{cb}|$. Using $|V_{td}| < 0.018$ one can obtain a lower limit on the t quark mass of $m_t > 60 GeV/c^2$.

5 Searches for $b \to s$ transition

Penguin decays of B mesons with a radiated photon or gluon probe the electroweak interaction at the one-loop level and provide a possible window on physics beyond the directly accessible mass scale. Searches for $b \to s$ transitions were performed through the reconstruction of exclusive final states. No signal is seen, leading to the limits shown in Table 6 [41].

These limits, as well as the limits obtained by CLEO [42], are close to the Standard Model predictions [43]. They start to constrain models involving more exotic phenomena.

Table 6. Limits on "penguin-type" B decays

Decay mode	N(90%CL)	BR(90%CL)
$B^0 \to K^+\pi^-$	< 9.4	$< 1.8 \cdot 10^{-4}$
$B^+ \to K^0_S\pi^+$	< 3.2	$< 1.0 \cdot 10^{-4}$
$B^0 \to K^{*+}(892)\pi^-$	< 2.3	$< 6.2 \cdot 10^{-4}$
$B^+ \to K^{*0}(892)\pi^+$	< 3.6	$< 1.7 \cdot 10^{-4}$
$B^0 \to K^0_S\rho^0$	< 2.3	$< 1.6 \cdot 10^{-4}$
$B^+ \to K^+\rho^0$	< 6.4	$< 1.8 \cdot 10^{-4}$
$B^0 \to K^{*0}(892)\rho^0$	< 7.7	$< 4.6 \cdot 10^{-4}$
$B^+ \to K^{*+}(892)\rho^0$	< 3.4	$< 9.0 \cdot 10^{-4}$
$B^0 \to K^0_S\phi$	< 2.3	$< 3.6 \cdot 10^{-4}$
$B^+ \to K^+\phi$	< 2.9	$< 1.8 \cdot 10^{-4}$
$B^0 \to K^{*0}(892)\phi$	< 2.3	$< 3.2 \cdot 10^{-4}$
$B^+ \to K^{*+}(892)\phi$	< 2.3	$< 1.3 \cdot 10^{-3}$
$B^0 \to K^{*0}(892)\gamma$	< 7.9	$< 4.2 \cdot 10^{-4}$
$B^+ \to K^{*+}(892)\gamma$	< 2.3	$< 5.2 \cdot 10^{-4}$

Conclusions

The investigations of the exclusive and inclusive semileptonic B decays lead to the consistent results for the CKM matrix element V_{cb}. The $|V_{cb}|$ values of

$$|V_{cb}| = 0.046 \pm 0.009 \ ,$$
$$|V_{cb}| = 0.042 \pm 0.008 \ ,$$
$$|V_{cb}| = 0.046 \pm 0.005 \ ,$$

are obtained from the studies of the $B^0 \to D^{*-}\ell^+\nu$, $B^0 \to D^-\ell^+\nu$, and $B \to \ell\nu X$ decays respectively.

An excess of 32±10 leptons above known backgrounds is observed beyond the endpoint of the momentum spectrum for B decays via $b \to c$ transitions. If interpreted as an evidence for the $b \to u$ transitions this 3.3 σ signal leads to a model dependent value of 0.10±0.02 for the ratio of the CKM matrix elements $|V_{ub}|/|V_{cb}|$ (the value is given for the ACM model[25]). This corresponds to the 95% CL lower limit of

$$|V_{ub}|/|V_{cb}| > 0.06 \ .$$

The upper limit on $|V_{ub}|/|V_{cb}|$ of 0.16 [26] is also model dependent.

A study of $B^0\overline{B}^0$ mixing was performed using an additional 70% more data. The value obtained for the mixing parameter r

$$r = 0.21 \pm 0.06$$

agrees perfectly with the original observation [5]. This result, the limit $m_t < 190 GeV/c^2$ and information about other CKM matrix elements restrict V_{td} to the interval

$$0.007 < V_{td} < 0.018$$

in the Standard Model with 3 generations.

Searches for the loop-induced $b \rightarrow s$ transitions are not yet sensitive to the values of V_{ts} expected in the Standard Model.

These results can be summarized in a graphical form. The unitarity of the CKM matrix requires

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0 \; .$$

This expression can be approximated by

$$V_{ub}^* + V_{td} \approx s_{12} V_{cb}$$

because $V_{ud} \approx 1$, $V_{tb} \approx 1$ and $V_{cd} \approx -s_{12}$, where s_{12}=0.22 is a sine of the well known Cabibbo angle. The three elements of the last equation form a triangle in the complex plane shown in Fig.14.

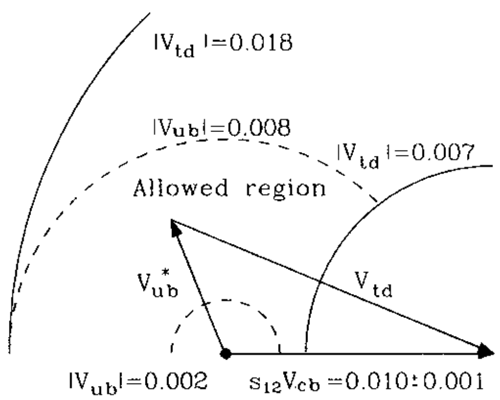

Figure 14: Unitarity triangle.

One side of the triangle is relatively well known: $s_{12}V_{cb}$=0.01 ± 0.001. The experimental constraints on V_{ub} and V_{td} are represented in the Fig. 14 by ellipses.

Recent studies of B mesons, especially the observation of the $B^0\overline{B}^0$ mixing and the evidence for the $b \rightarrow u$ transitions, put severe constraints on the parameters of the quark sector of the Standard Model. There is almost no flexibility left and new experiments have a good chance to reveal its incompleteness or provide important confirmations.

Aknowledgements

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References

[1] N.Cabibbo, Phys.Rev.Lett. **10**,531 (1963).

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

[3] H. Schröder, Proc. of the 24^{th} International Conference on High Energy Physics, Munich (1988).

[4] D.Bertoletto *et al.* (CLEO) Preprint CLNS 89/887.

[5] H.Albrecht et al (ARGUS), Phys.Lett. **192B**, 245 (1987).

[6] H.Albrecht et al (ARGUS), Phys.Lett. **197B**, 452 (1987).

[7] H.Albrecht et al (ARGUS), Phys.Lett. **219B**, 121 (1989).

[8] D.L.Kreinick, These Proceedings.

[9] J. Adler *et al.* (MARK III), Phys. Lett. **208B**, 152 (1988).

[10] D. Bortoletto *et al.* (CLEO), CLNS 89/922 (1989).

[11] M.Wirbel, B.Stech and M.Bauer, Z.Phys. **C29**, 637 (1985).

[12] J.G.Körner and G.A.Schuler, Z.Phys. **C38**, 511 (1988).

[13] N.Isgur, D.Scora, B.Grinstein and M.B.Wise, Phys.Rev. **D39** (1989) 799.

[14] T.Altomari and L.Wolfenstein, Phys.Rev. **D37**, 681 (1988).

[15] H. Albrecht *et al.* (ARGUS), DESY 89-082 (1989).

[16] J. Adler *et al.* (MARK III), Phys. Rev. Lett. **60**, 89 (1988).

[17] F. Schöberl and H. Pietschmann, Europhys. Lett. **2**, 583 (1986).

[18] A.A. Ovchinnikov and V.A. Slobodenyuk, IHEP 89-10 (1989).

[19] J.M. Cline, W.F. Palmer and G. Kramer, DESY 89-029 (1989).

[20] M.A. Shifman, Proceedings of the 1987 International Symposium on Lepton and Photon Interactions at High Energies, Hamburg, p. 289 (1987).

[21] A. Soni, Phys. Rev. Lett. **53**, 1407 (1984).

[22] A. Bean *et al.* (CLEO), Phys. Rev. Lett. **58**, 183 (1987);
E.H. Thorndike and R.A. Poling, Phys. Rep. **157**, 183 (1988).

[23] S. Abachi *et al.* (HRS), Phys. Lett. **212B**, 533 (1988).

[24] H. Albrecht *et al.* (ARGUS), DESY 89-117 (1989).

[25] G.Altarelli *et al.*, Nucl.Phys. **B208**, 365 (1982).

[26] J.C.Gabriel, Dr.rer.nat. Thesis, Heidelberg University (1988);
J.Spengler, Proc. of the 24th International Conference on High Energy Physics, Munich (1988);
M.V.Danilov, Preprint ITEP 88-180, Moscow (1988).

[27] A.Bareiss and E.A.Paschos, Preprint DO-TH 89/1,(1989).

[28] Crystal Ball Collab., K.Wachs *et al.*, Z.Phys. **C42** (1989) 33.

[29] R.Rückl, Habilitationsschrift, Universität München, Munich (1984).

[30] P.Haas *et al.*,(CLEO) Phys.Rev.Lett. **55**, 1248 (1985);
H.Albrecht *et al.*,(ARGUS) Phys.Lett. **B162**, 395 (1985)
H.Albrecht *et al.*,(ARGUS) Phys.Lett. **B199**, 451 (1987).

[31] T.Ruf,Dr.rer.nat. Thesis, Karlsruhe Univ. (1989).

[32] H.Albrecht *et al.*,(ARGUS) Phys.Lett. **B209**, 119 (1988).

[33] D.L.Kreinick, Proc. of the 24th International Conference on High Energy Physics, Munich (1988).

[34] A.V.Dobrovolskaya et al. Preprint ITEP 108-89, Moscow (1989).

[35] M.Artuso et al (CLEO), Phys.Rev.Lett. **63**, 2233 (1989).

[36] M.K.Gaillard and B.W.Lee, Phys.Rev. **D10** (1974) 897;
J.S.Hagelin, Phys.Rev. **D20**, 2893 (1979).

[37] G.Altarelli, Proc. of the Int. Europhysics Conference on High Energy Physics, Uppsala (1987) p.1002.

[38] P.Sinervo (CDF), These Proceedings.

[39] K.Kleinknecht and B.Renk,Z.Phys. **C34**, 209 (1987).

[40] G.Costa *et al.* Nucl.Phys. **B297**, 244 (1988).

[41] H. Albrecht *et al* (ARGUS), DESY 89-086 (1989);
H. Albrecht *et al* (ARGUS), DESY 89-096 (1989).

[42] P.Avery *et al.* (CLEO), Preprints CLEO 89-2, CLEO 89-4 (1989).

[43] M.B.Gavela *et al.*, Phys.Lett. **154B**, 425 (1985);
L.-L.Chau and H.Y.Cheng, Phys.Rev.Lett. **59**, 958 (1987);
N.G.Deshpande *et al.*, Phys.Rev.Lett. **59**, 183 (1987).

Additional page:

After the first line of chapter 2.4 the following formulae should be inserted

$$\Gamma(B \to l^+ \nu X) = \frac{G_F^2 m_b^5}{192\pi^3}(f_c|V_{cb}|^2 + f_u|V_{ub}|^2) \ ,$$