RECENT RESULTS FROM CLEO

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ABSTRACT

I present a selection of recent CLEO results. This talk covers mostly B physics, with one tau result and one charm result. I do not intend to be comprehensive; all CLEO papers are available on the web at http://www.lns.cornell.edu/public/CLNS/CLEO.html.

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In this talk I will discuss four B physics topics, and two others:

- The semileptonic branching ratio and the "charm deficit."
- Hadronic decays and tests of factorization.
- Rare hadronic decays and "CP engineering."
- Measurement of V_{cb} using $B \to D l \nu$.
- A precision measurement of the τ Michel parameters.
- The possible observation of $c\bar{s}$ annihilation in hadronic D_s decay.

One theme that will run throughout is the need, in an era of 10^{-5} branching fraction sensitivity and 1% accuracy, for redundancy and control over systematic error.

B Semileptonic Decay and the Charm Deficit

Do we understand the gross features of B decay? The answer to this question is important for two reasons. First, new physics may lurk in small discrepancies. Second, B decays form the primary background to rare B processes, and an accurate understanding of backgrounds will be important to the success of experiments at the upcoming B factories.

Compare measurements of the semileptonic branching fraction at LEP with those at the $\Upsilon(4S)$ (see figure 1) and with theory. One naïvely expects the LEP result to be 0.96 of the 4S result, because LEP measures an inclusive rate, which is pulled down by the short Λ_B lifetime. In fact, the ratio of results is 1.09 ± 0.042, about 2σ high. The LEP N_c measurement is also higher than CLEO's, but the interpretation is also complicated by the mixture of particles produced at high energy. I will not discuss the LEP data, but instead will consider possible solutions to what appears to be a 2-3 standard deviation disagreement between CLEO and theory. The line in figure 1 is a result of perturbative QCD, with the band resulting from variation of quark masses and renormalization scale.

The contributions to the CLEO measurement of N_c are shown in table 1. It is usually assumed that the semileptonic rate can be reliably calculated. Therefore, to decrease the semileptonic branching fraction one must

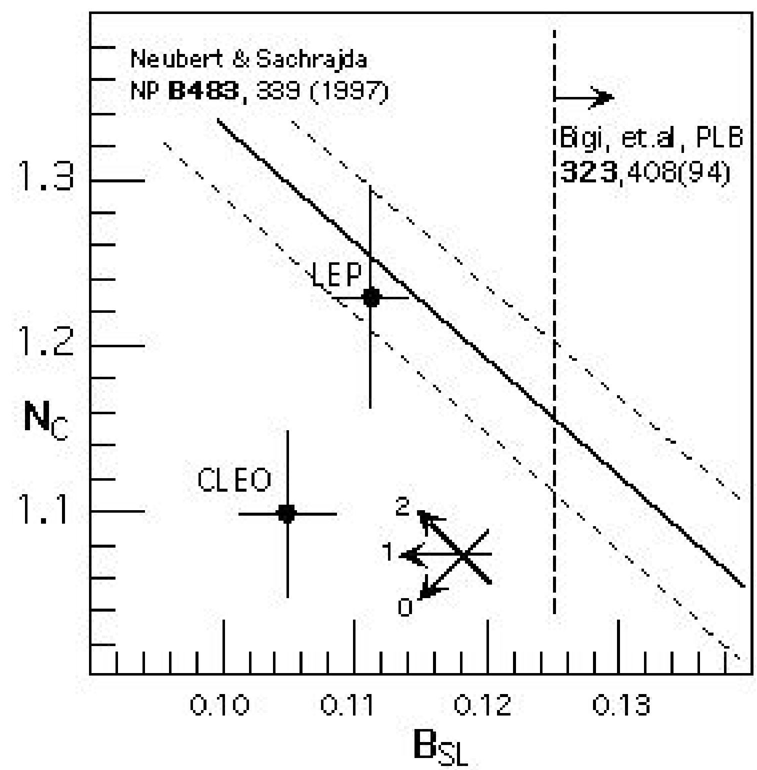

Figure 1. Prediction and measurement of the B semileptonic branching ratio and the number of charmed particles per B decay.[1,2]

increase the hadronic decay rate. The three lines with arrows in figure 1 show the direction the theoretical prediction moves if the increased hadronic rate is into final states with 0, 1, or 2 charmed quarks. The most efficient way to achieve agreement is via an extra ~10% rate into charmless final states.

A theoretical enhancement of $b \to c\bar{u}d$ (*e.g.*, due to a problem with the QCD calculation) moves the line horizontally to the left. An enhancement of $b \to c\bar{c}s$ (upper vertex production of charm) moves the line up and to left (*i.e.*, does not resolve the problem). An enhancement of final states without charm (*e.g.*, $b \to s\gamma$ or $b \to d\gamma$) moves the line in the desired direction, but requires some unexpectedly large penguin processes. Of course, it is possible that the problem lies with some unknown experimental error, such as the use of an incorrect $D^o \to K\pi$ branching ratio (most charm

One c quark		**Two c quarks**	
$B \to D^o X$	63.6 ± 3.0 %	$B \to \Psi X$	1.6 ± 0.2 %
$B \to D^+ X$	23.5 ± 2.7 %	$B \to \Psi' X$	0.7 ± 0.1 %
$B \to D_s^+ X$	12.1 ± 1.7 %	$B \to \chi_{c1} X$	0.8 ± 0.1 %
$B \to \Lambda_c^+ X$	3.9 ± 2.0 %	$B \to \chi_{c2} X$	0.5 ± 0.2 %
$B \to \Xi_c^{+,o} X$	2.0 ± 1.0 %	$B \to \eta_c X$	< 1.8 %

Table 1. Summary of experimental contributions to N_c. The total is $N_c = (110 \pm 5)\%$.

measurements rely on this number). This particular quantity has been verified to be correct.

We can perform some consistency checks to eliminate obvious sources of error. Consider the various topological decay modes of B mesons, shown in table 2. The sum is about 2σ low. If one supposed that the problem were entirely due to a mismeasurement of B_{SL}, 12.5% would be required. If it were due to an error in the $D^{o} \to K\pi$ branching ratio (this mode normalizes most $b \to c$ measurements), a 15% reduction would be needed. Both possibilities are unlikely. The measured $b \to c\bar{u}d$ fraction, 0.41 ± 0.05, agrees with next to leading order QCD (0.42 ± 0.04). The $b \to c\bar{c}s$ fraction has recently been remeasured by CLEO to be 0.241 ± 0.032. This value is significantly larger than previous results, due to the identification of charm production from the "upper vertex." The value remains smaller than theory, 0.32 ± 0.05[3]. In any case, an enhanced ccs rate does not resolve the charm deficit problem.

The observation of upper vertex charm production (see figure 2) is important to our understanding of backgrounds to rare B decay processes. Monte Carlo programs must have the correct description of charm production if the data is to be correctly modeled. CLEO measures this process[4] using correlations between the lepton and charm from B decay. The two particles can come from the same B (via $b \to c l^{+} \nu$)or different Bs. In the first case, c and l^{+} appear together - in the latter, c and l^{-}. There are

$ce\nu$, $c\mu\nu$	$2 * B_{SL} = 2 * (10.49 \pm 0.46)\%$	
$c\tau\nu$	$0.25 * B_{SL}$	phase space suppression
$cu\bar{d}$	$(4.0 \pm 0.4) * B_{SL}$ [5]	
D_s	$(10.0 \pm 2.7)\%$	
$D^{\pm}$, D^{o}	$(7.9 \pm 2.2)\%$	Upper vertex charm production
$cc\bar{X}$	$(3.0 \pm 0.5)\%$	
sg	$< 6.8\%$	Theory predicts ~1%
Sum	$(87.5 \pm 5.9)\%$	

Table 2. B decay branching fractions into topologically distinct final states.

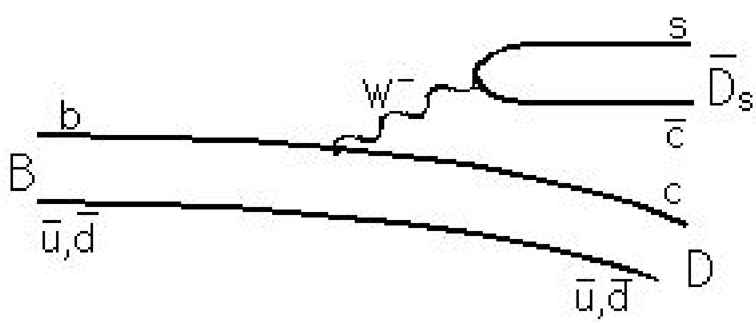

Figure 2. The Feynman diagram for “upper vertex” charm production.

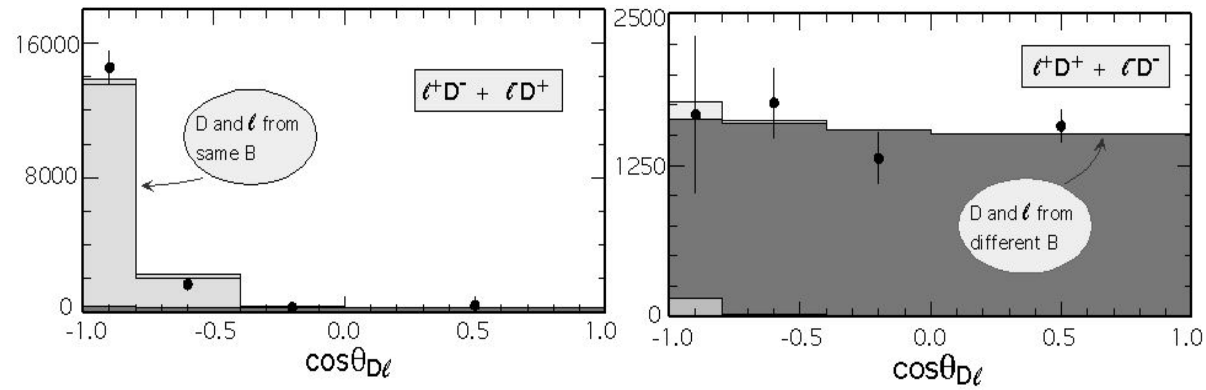

Figure 3. The D-ℓ angular correlations for like and unlike sign pairs.

angular correlations as well. If the lepton and charm come from the same B, they tend to go back to back. If from different Bs, there is almost no correlation (because the B is spin 0 and nearly at rest).

The CLEO data is shown in figure 3 for same sign and opposite sign pairs. A clear difference is seen (leptons from charm decay were eliminated with a momentum cut.). The analysis is done two ways, the first ignores the angular correlation and merely counts the number of events of each kind. This method yields three equations in three unknowns:

$$N(\ell^+\bar{D}X) = \bar{b}\to\ell^+\bar{D}X + b\to\bar{D}X = \bar{D}\text{ from same B as }\ell + \bar{D}\text{ from other B (u.v.)}$$

$$N(\ell^+DX) = 0 + b\to DX = \text{no } b\to D\ell^+ + D\text{ from other B (l.v.)}$$

$$N(DX) = b\to DX + \bar{b}\to DX = b\to DX + b\to\bar{D}X$$

This method uses the angular correlations only to verify that there is no significant $D\ell^+$ from the same B, as can be seen in figure3. CLEO's result is $b\to\bar{D}X$ / $b\to DX$ = 0.100±0.026±0.016, or $\mathcal{B}(b\to\bar{D}X)$ = 0.079±0.022.

To remind you why we are confident that we have the correct semileptonic branching ratio, I show here a check on the systematic error that was reported last year.[6] One can measure the single lepton inclusive spectrum, which includes both B and D decays. Then, one fits to the sum of both contributions. This method has good statistics, but depends on the models for calculating the spectral shapes. Alternatively, one can compare opposite-sign dilepton events with like-sign events. The former is the signal, due to both B's decaying semileptonically. The latter is the background, from one B decay and one charm decay. It has worse statistics but different systematic errors. The two results are compared in figure 4 and table 3. Both the inferred semileptonic branching ratios and the shapes of the lepton spectra agree between the two methods, indicating that there is not a large systematic problem with our measurement.

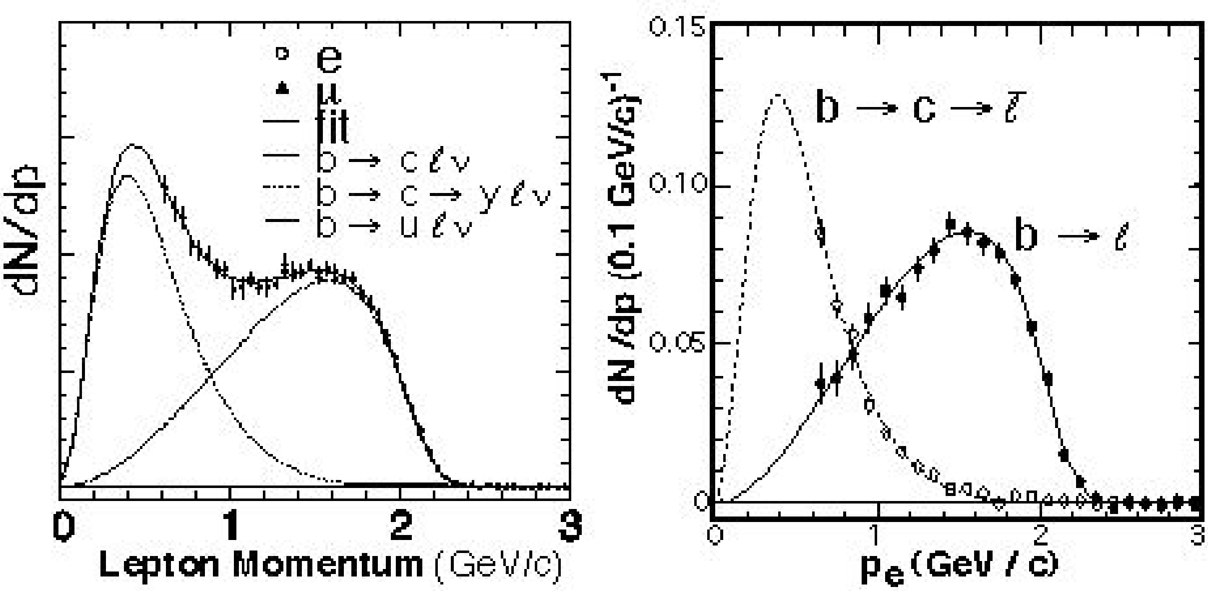

Figure 4. Momentum spectrum of lepton from $b \to c l \nu$ and $b \to c \to s l \nu$.
a. Events with one detected lepton. **b**. Events with two leptons.

Method	Result	Model
Fit to spectrum in single lepton events	$(10.48 \pm 0.07 \pm 0.33)\%$ $(10.87 \pm 0.10 \pm 0.33)\%$	ACCM ISGW
Fit to spectrum in dilepton events	$(10.49 \pm 0.17 \pm 0.43)\%$	

Table 3. B semileptonic branching fractions using single lepton and dilepton events.

Hadronic Decays and Tests of Factorization

If the recombination of quarks into hadrons is independent of the environment, then factorization holds. Factorization allows one to write process amplitudes as the product of terms, as illustrated in figure 5 for $B \to D\pi$. In analogy to semileptonic decays, for which the matrix element is proportional to a product of currents:

$$\Gamma_{SL} \propto |<D|J_\mu|B><\nu|\gamma_\mu(1-\gamma_5)|l>|^2 \quad \text{(semileptonic)}$$

$$\Gamma_{HAD} \propto |<D|J_\mu|B><\pi|J_\mu|0>|^2 = |a_1 F_{BD} f_\pi|^2 \quad \text{(spectator)}$$

$$\Gamma_{HAD} \propto |<\pi|J_\mu|B><D|J_\mu|0>|^2 = |a_2 F_{B\pi} f_D|^2 \quad \text{(color suppressed)}$$

where F_{BD} and $F_{B\pi}$ are transition form factors, and f_π and f_D are the meson decay constants.[7] The parameters are process dependent and must be measured. In particular, $a_1 \neq a_2$. If factorization holds, each parameter (*e.g.*, a_1) depends only on the kinematics of part of the process. Factorization can be tested by comparing $B \to D\pi$ with $B \to D l \nu$ at the proper kinematic point, or by comparing the two contributions to $B \rightarrow D\pi$ in figure 5, using QCD to evolve the parameters to the different kinematic points (this evolution is model dependent).

The spectator and colored suppressed diagrams can be compared by measuring their interference when the final states are the same. The color suppressed diagram (so called because there is a suppression imposed by the requirement that hadrons be color singlets) is difficult to be measured accurately by itself. In addition, interference also measures the relative sign of the two amplitudes.

Let us begin with the charm system. The ratio of charged to neutral D meson lifetimes, $\tau_+ / \tau_o \sim 2.5$, results from the destructive interference between the two diagrams:

$D^o \rightarrow K^- \pi^+$	$\lvert a_1 \rvert^2$	Spectator only
$D^o \rightarrow K^o \pi^o$	$\lvert a_2 \rvert^2$	Color suppressed only
$D^+ \rightarrow K^o \pi^+$	$\lvert a_1 + a_2 \rvert^2$	Spectator and color suppressed

The lifetime ratio tells us that $a_2 / a_1 \sim -0.45 \pm 0.05$ in the charm sector.

The corresponding lifetime ratio for bottom mesons, $\tau_{B+} / \tau_{Bo} = 1.06 \pm 0.04$. Does this mean that interference effects are small in the B system? We would like to measure several processes: $B^o \rightarrow D^+ \pi^-$, $B^o \rightarrow D^+ \rho^-$, and $B^o \rightarrow D^+ a_1^-$ (also D*), and $B^+ \rightarrow D^o \pi^-$, $B^+ \rightarrow D^o \rho^-$, and $B^+ \rightarrow D^o a_1^-$. Until now, only combined measurements were possible (see figure 6).

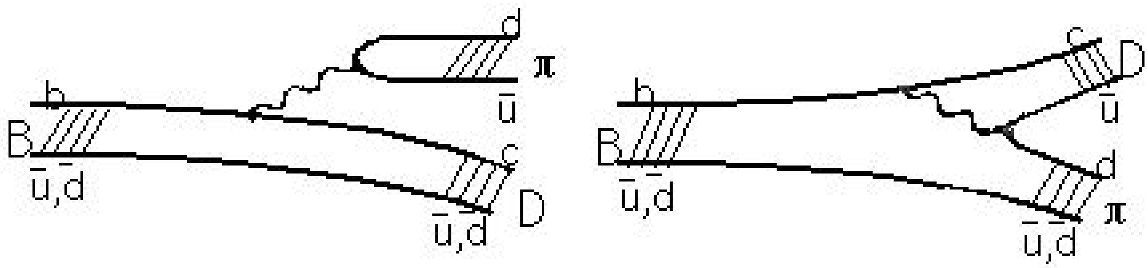

Figure 5. Illustration of factorization for the spectator and color suppressed diagrams leading to $B \to D\pi$.

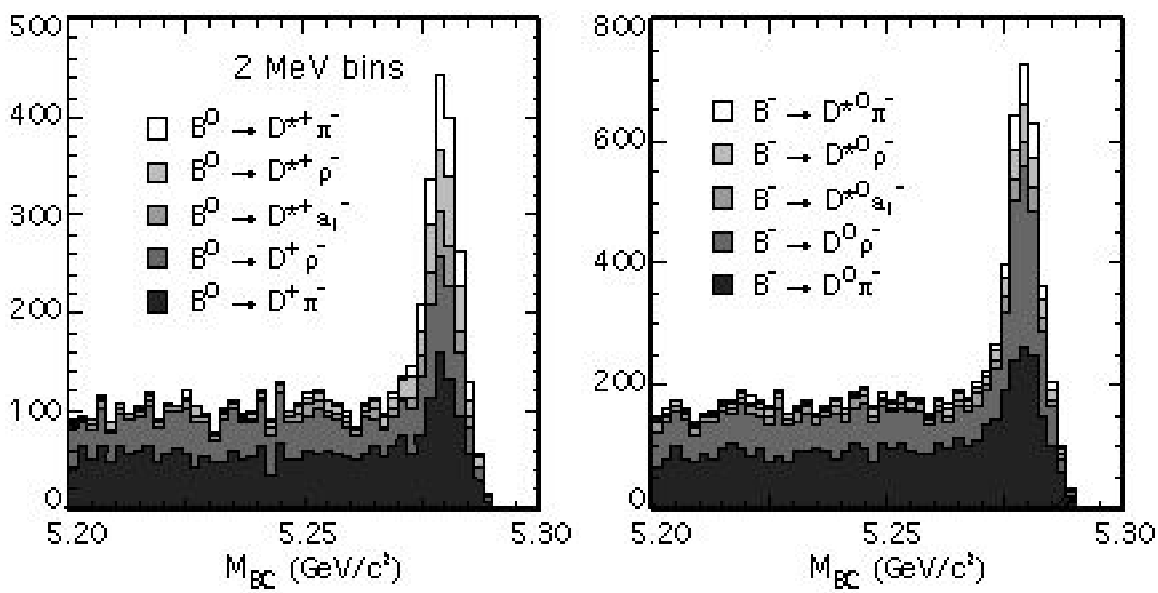

Figure 6. Beam constrained mass distribution for fully reconstructed two-body B^0 and B^+ decays.

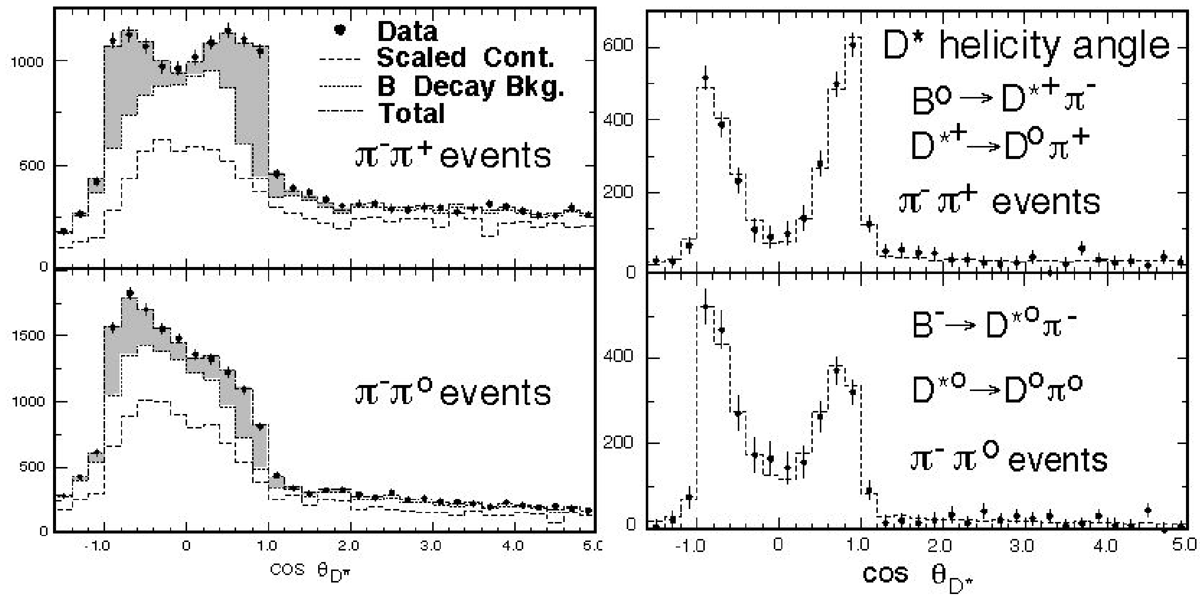

Figure 7. D* helicity angle in $B^o \rightarrow D^{*+}\pi^-$ and $B^- \rightarrow D^{*o}\pi^-$, before and after background subtraction.

Full reconstruction suffers from low statistics, due to the small branching ratios. However, combining different modes to improve the statistics dilutes the physics sensitivity, because each mode is at a different kinematic point, and because comparisons between modes is not possible. CLEO has a new result[8] for $B \rightarrow D^*\pi$ using partial reconstruction. In the partial reconstruction method, no attempt is made to observe the final state D meson, avoiding one branching ratio penalty: $B \rightarrow D^* \pi \rightarrow \cancel{D}\pi_s \pi$.

Measuring only the two pions gives a 0-C fit. Background is separated from the signal by taking advantage of the spin alignment of the D* (see figure 7). Events outside the physical region are background. The CLEO result is $\mathcal{B}(B^o \rightarrow D^{*+}\pi^-) = (2.79 \pm 0.11 \pm 0.21 \pm 0.05) \times 10^{-3}$ and $\mathcal{B}(B^- \rightarrow D^{*o}\pi^-) = (4.14 \pm 0.42 \pm 0.34 \pm 0.18) \times 10^{-3}$. The ratio is 1.48 ± 0.24 which, when combined with Neubert's prediction of $1.07 * [1 + (1.36\pm0.20)*(a_2/a_1)]^2$, yields $a_2/a_1 = 0.12 \pm 0.07$.

Thus, the interference appears to be small and constructive. The uncertainty is dominated by the experimental measurement, but I have also included a 15% uncertainty in the unmeasured f_{D^*}. This result is consistent with previous measurements, which summed over decay modes.

Rare Hadronic Decays and "CP Engineering"

Rare hadronic decays of B mesons have been proposed as probes of CP violation. If the CKM model is the correct description, then there is a single CP violating parameter, and the various CP violating amplitudes are related. For a review, see Buras and Fleischer.[9]

Indirect CP violation (via $B\bar{B}$ mixing) might be observable via $B\to\pi\pi$, which is proportional to $\sin2\alpha$ (conventional B factory measurements are sensitive to $\sin2\beta$). Direct CP violation (in the decay) might be observable in self tagging modes, such as $B\to K\pi$. Knowledge of strong phase shifts is needed to extract the physics, because the CP violating asymmetry is proportional to $\sin\gamma\cdot\sin\delta$.

If one assumes SU(3) symmetry and ignores the effect of electroweak penguin diagrams, there is a nice triangle relation[10] between B decay amplitudes which allows a measurement of 2γ, as shown in figure 8. Unfortunately, the E-W penguins make the situation much more complicated. I will not discuss this, but present here some new experimental results on the modes of interest. The branching fractions are in the 10^{-5} range, so their measurement requires some care.

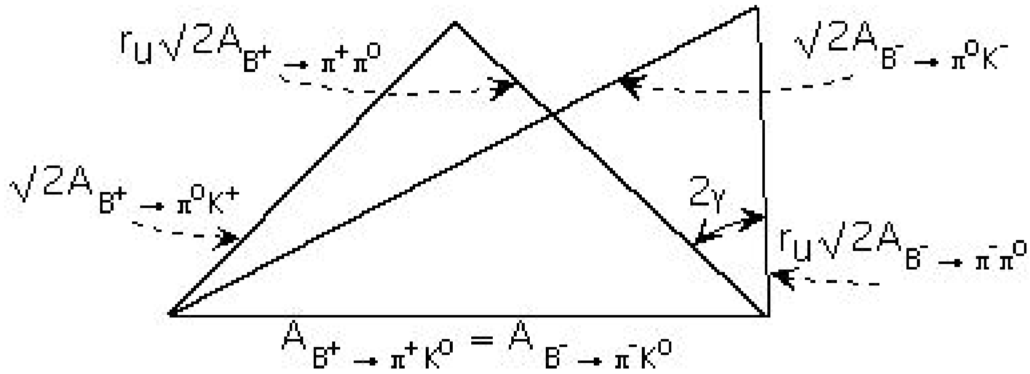

Figure 8. Amplitude triangles for two-body hadronic B decay, showing the dependence on 2γ.

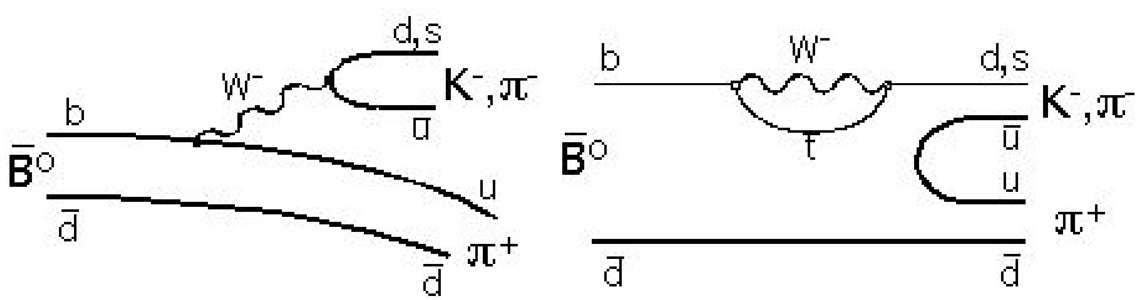

Figure 9. Spectator and QCD penguin diagrams contributing to $B \to \pi^+\pi^-$ and $K^+\pi^-$.

CLEO has measured $B \to \pi\pi$ and $K\pi$ in several charge states. It is expected that spectator (color favored and color suppressed) and QCD penguin diagrams should dominate (see figure 9). In the $K\pi$ mode, penguin ($V_{tb}V_{ts}$ ~ 0.04) should dominate over spectator ($V_{ub}V_{us}$ ~ 0.0007). In the $\pi\pi$ mode, the reverse should hold ($V_{ub}V_{ud}$ ~ 0.003, compared to $V_{tb}V_{tds}$ ~ 0.001). The spectator diagram does not contribute to the KK mode. Penguins ($V_{tb}V_{td}$ ~ 0.001) can produce K^oK^o or K^-K^o, but K^+K^- is dynamically suppressed (W exchange).

In 1995, CLEO reported[11] $\mathrm{B}(B \to h^+\pi^-) = 1.8^{+0.6+0.2}_{-0.5-0.3} \times 10^{-5}$ ($K^+\pi^-$ and $\pi^+\pi^-$ not separately reported). With 30% more data and improved particle identification, the $K^+\pi^-$ mode is now significant (figures 10 and 11). One important feature is that $\mathrm{B}_{K\pi} \geq \mathrm{B}_{\pi\pi}$, indicating that penguin processes are important.

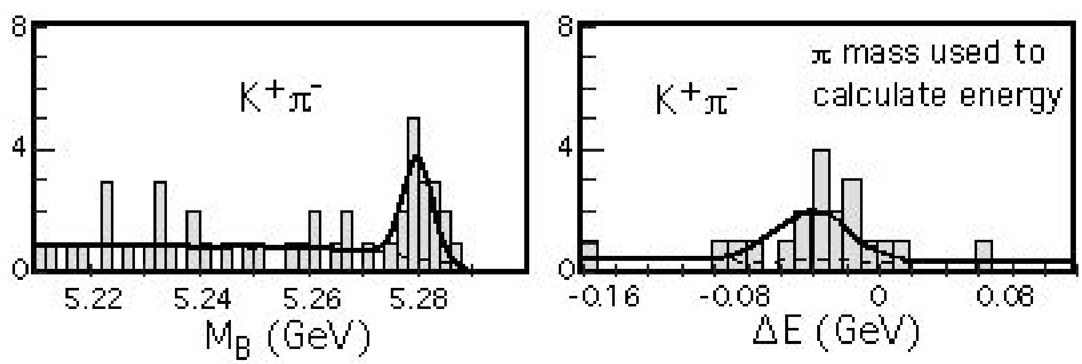

Figure 10. Beam constrained mass and energy difference for $B \to \pi^+\pi^-$ and $K^+\pi^-$ together, calculated as $\pi^+\pi^-$. Only half of the events appear in projections, due to cuts.

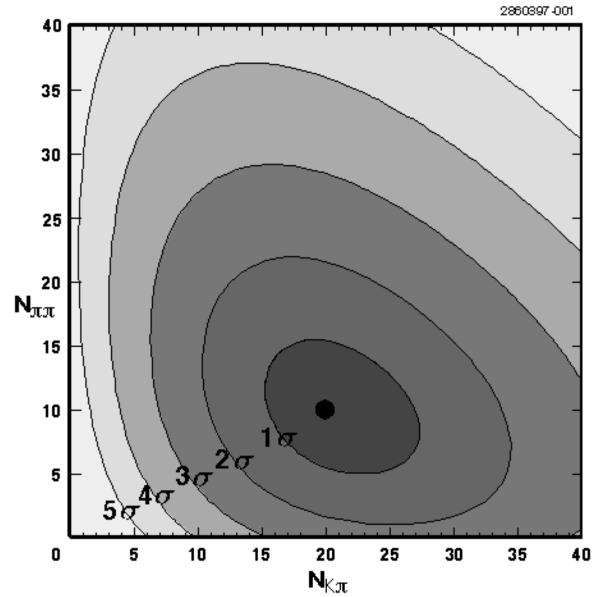

Figure 11. $K^+\pi^-$ *vs* $\pi^+\pi^-$ event confidence contours.

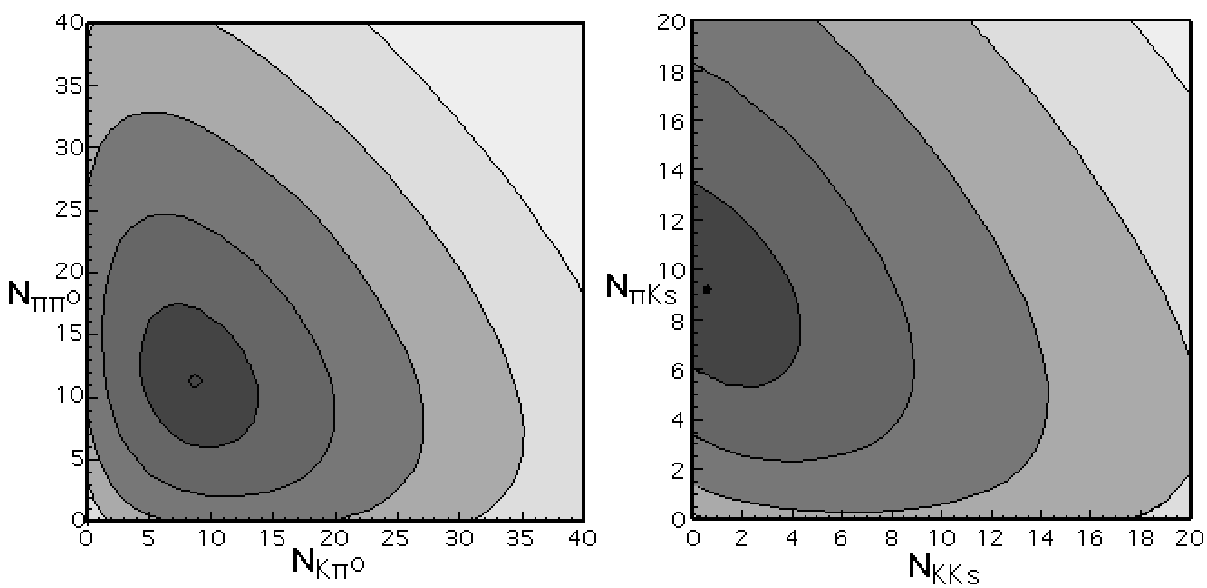

Figure 12. $K^+\pi^o$ *vs* $\pi^+\pi^o$ and K^+K_s *vs* $\pi^+ K_s$ event confidence contours

Modes with neutral K and π are also seen. The confidence contour plots (figure 12) for $K\pi^o$ *vs* $\pi\pi^o$ and KK_s *vs* πK_s are similar. The strength of the data for these modes is similar to that for the charged modes two years ago - the combined results are significant, but not each mode separately. The KK_s mode is small, as expected. The results are summarized in table 4.

Mode	**Yield**	**#σ**	**B (× 10^{-5})**	**U.L.**
$K^+\pi^-$	$21.7^{+6.8}_{-6.0}$	5.6	$1.5^{+0.5+0.1}_{-0.4-0.1} \pm 0.1$	
$K^+\pi^o$	$8.7^{+5.3}_{-4.2}$	2.7		1.6
$K^o\pi^+$	$9.2^{+4.3}_{-3.8}$	3.2	$2.3^{+1.1+0.2}_{-1.0-0.2} \pm 0.2$	4.4
$K^o\pi^o$	$2.3^{+2.2}_{-1.5}$			4.0
$\pi^+\pi^-$	$10.0^{+6.8}_{-6.0}$	2.2		1.5
$\pi^+\pi^o$	$11.3^{+6.8}_{-6.2}$	2.8		2.0
$\pi^o\pi^o$	$1.2^{+1.7}_{-0.9}$			0.9
K^+K^-	$0.0^{+1.8}_{-0.0}$	0		0.4
K^+K^o	$0.6^{+6.8}_{-0.6}$	0.2		2.1
K^oK^o	0			1.7
$h^+\pi^-$	$31.7^{+6.4}_{-7.8}$	7.8	$2.2^{+0.6}_{-0.5}$	
$h^+\pi^o$	$20.0^{+6.8}_{-5.9}$	5.5	$1.6^{+0.6+0.2}_{-0.5-0.2} \pm 0.1$	
h^+K^o	$9.8^{+4.5}_{-4.0}$	4.4	$2.4^{+1.1+0.2}_{-1.0-0.2} \pm 0.2$	

Table 4. Branching fractions and upper limits for $B \to K\pi$ and $\pi\pi$.

Other Rare Hadronic Decays (B_{SL}-N_c Revisited)

CLEO has measured other rare hadronic decays. The modes ωh^+, ηh^+, and $\eta' h^+$ are of particular interest, because they are sensitive to QCD penguin processes. As with the $K\pi$ modes, we can only separate π from K statistically (by fitting distributions). The $\eta' h^+$ data is shown in figures 13 and 14. It appears to be dominated by $\eta' K^+$. The branching fractions are listed in table 5. The result is surprisingly large, and has generated some interest. Several explanations (see figure 15) have been put forward:

- Interference between hadronic penguins with $g \to u\bar{u}$ and $g \to s\bar{s}$.[12]
- A cc component of the η'.[13,14]
- $cc \to$ glue $\to$ light mesons.
- Final state interactions ($\eta' K$ scattering).
- Anomalous $\eta' gg$ coupling (glueball).[15]

Unusually large $b \to c\bar{c}s$, without visible charm, might explain a low B_{SL} without ruining N_c.[16]

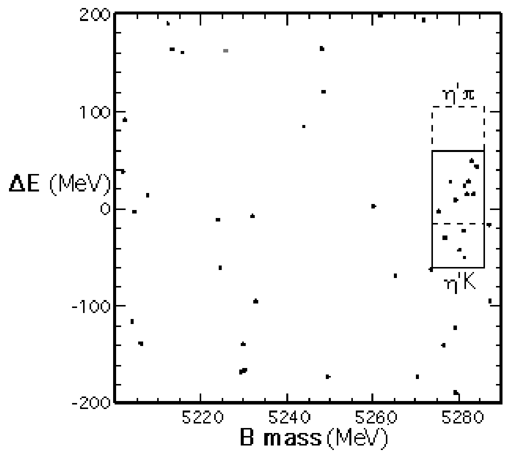

Figure 13. Beam constrained mass and ΔE for $B \rightarrow \eta' h^+$ events.

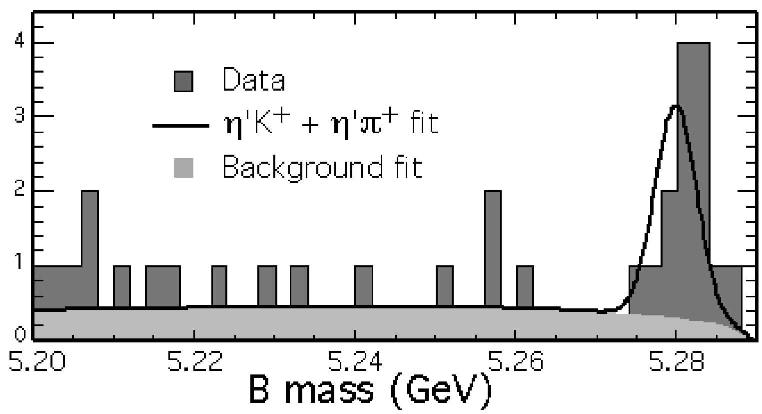

Figure 14. Projection of $B \rightarrow \eta' h^+$ events onto the mass axis.

Mode	**Yield**	**#σ**	**B** $(\times 10^{-5})$	**U.L.**
$\omega\pi^+$	$9.5^{+5.3}_{-4.2}$	3.3	$1.2^{+0.7}_{-0.5} \pm 0.2$	
ωK^+	$8.6^{+4.9}_{-3.9}$	2.9	$1.2^{+0.7}_{-0.5} \pm 0.2$	
ηh^+	0			0.8
$\eta'\pi^+$	$1.3^{+2.0}_{-1.1}$	2.0		4.5
$\eta' K^+$	$12.0^{+4.1}_{-3.4}$	5.8	$7.1^{+2.5}_{-2.1} \pm 0.9$	

Table 5. Branching fractions and upper limits for $B \rightarrow \omega h$, ηh, and $\eta' h$.

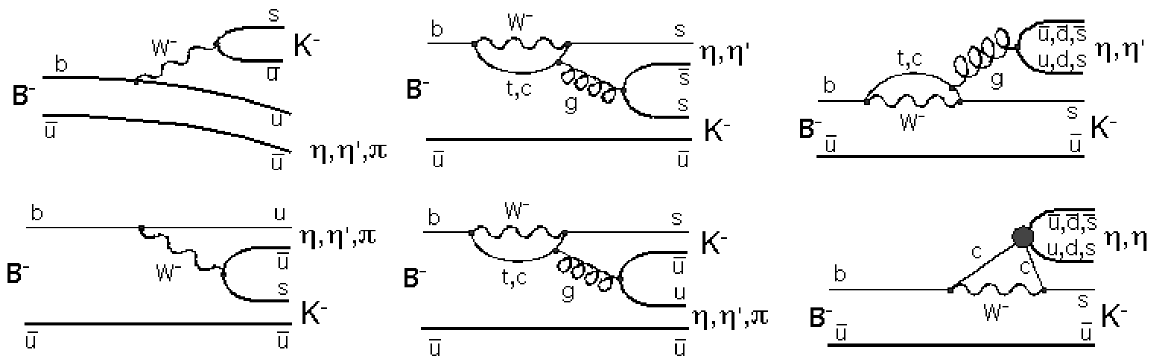

Figure 15. Feynman diagrams contributing to $B \rightarrow \eta' K$.

V_{cb} from $B \rightarrow Dl\nu$ Using Neutrino Reconstruction

In heavy quark effective field theory, the spin of the heavy quark decouples from the light degrees of freedom. This implies that B decays to final states with a D meson should behave similarly to those with a D^*. In particular, the semileptonic decays $B \rightarrow Dl\nu$ and $B \rightarrow D^*l\nu$ should have the same form factors and provide equally valid measures of V_{cb}. Unfortunately, the former decay is not as useful as the latter, because its rate near the kinematic point of interest, maximum q^2 (zero charm recoil) is suppressed by a centrifugal barrier. Maximum q^2 is theoretically the best place to measure V_{cb}, because the corrections due to finite quark mass are smallest there. In addition to the small rate, $B \rightarrow Dl\nu$ suffers from background contamination compared with $B \rightarrow D^*l\nu$, which can be tagged using the $D^* \rightarrow D\pi$ decay.

Nevertheless, the measurement of $B \rightarrow Dl\nu$ is interesting as a test of HQET. Previous measurements have suffered from poor signal to background, but CLEO has used the neutrino reconstruction technique to improve the measurement.[17] This technique was developed by CLEO to find the rare decays $B \to \pi l \nu$ and $B \to \rho l \nu$.[8] Because the $\Upsilon(4S)$ decays only to $B\bar{B}$ pairs, the momenta and energies of the other B meson's decay products are used to determine the neutrino's 4-momentum. This can be done without excessive loss of efficiency which, in exclusive B meson reconstruction, results largely from combinatorial backgrounds. The

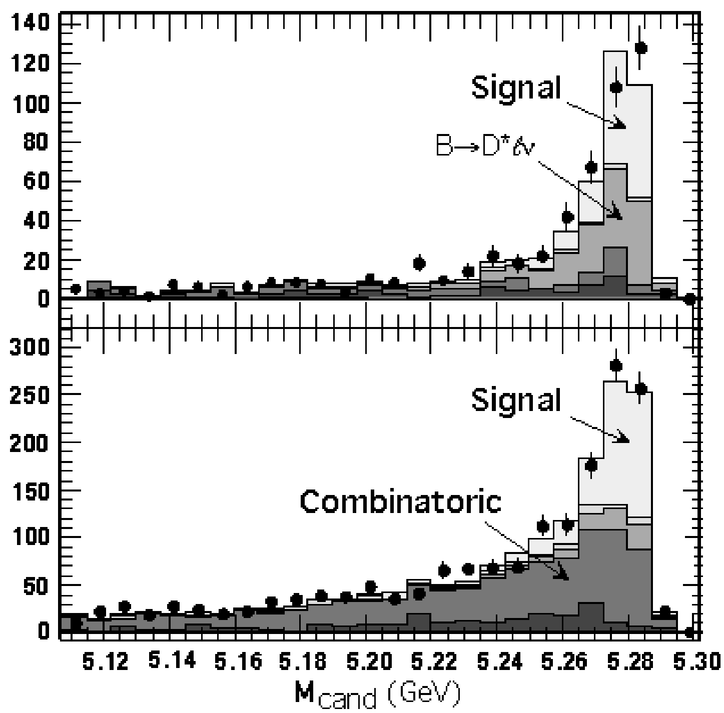

Figure 16. Reconstructed B mass from $B \to D l \nu$, showing background contributions.

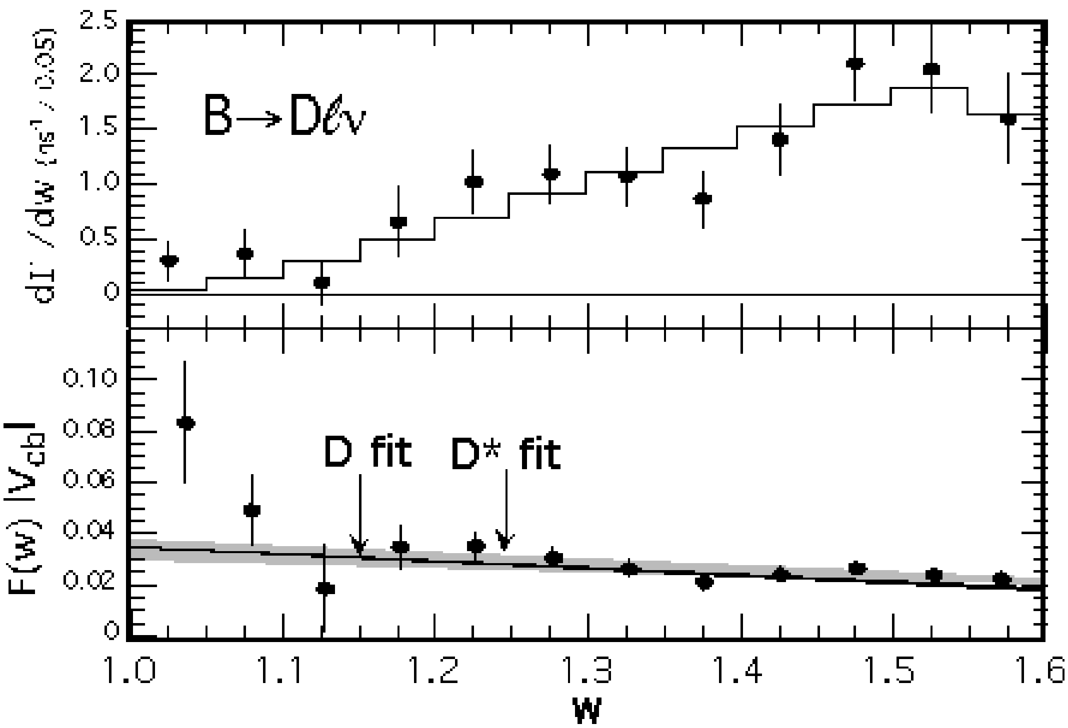

Figure 17. W dependence of $B\to Dl\nu$ data and form factor. The $B\to D^*l\nu$ form factor is overlaid.

resulting reconstructed B mass is shown in figure 16. The signal to background is 5 times better than with the old method.

The w distributions of the data and the decay form factor (fit to a straight line) are shown in figure 17. W is the γ (time dilation) factor of the c quark in the b quark rest frame; w=1 corresponds to maximum q^2. The $B\to D^*l\nu$ form factor is overlaid, displaying the consistency between the two measurements.

The new CLEO result is $F_D(1)|V_{cb}| = (3.37\pm0.44\pm0.48+0.53-0.12)\times10^{-2}$. $F_D(1)$ is the decay form factor at w=1, calculated to be 0.91 ± 0.06.[19] Compare this result with other measurements of V_{cb}:

$B \rightarrow D l \nu$ $(3.72 \pm 0.40 \pm 0.27) \times 10^{-2}$

$B \rightarrow D^* l \nu$ $(3.86 \pm 0.27 \pm 0.13) \times 10^{-2}$

$B \rightarrow X l \nu$ $(3.88 \pm 0.08 \pm 0.28) \times 10^{-2}$

$b \rightarrow X l \nu$ $(4.10 \pm 0.04 \pm 0.29) \times 10^{-2}$

The inclusive and exclusive measurements agree, as do D and D^* exclusive.

The Michel Parameters of the τ

CLEO has several million τ lepton pairs. This makes possible precision tests of the weak interactions in τ decay, using methods developed almost 50 years ago to study the muon.[20,21] Figure 18 illustrates the amount and cleanliness of the data available in the purely leptonic decay, $\tau \rightarrow l \nu \nu$. Angular distributions such as the one shown were first used to verify the V-A nature of the weak interactions. Now, they are sensitive to possible new phenomena, such as Higgs or right handed W bosons.

Figure 19 shows some recent measurements of the τ decay parameters. The new CLEO results[22] reduce the errors by about a factor of four. Table 6 compares τ and μ Michel parameters. The limit on M_{W_R} (260 GeV, for arbitrary mixing) from the τ data approaches that (406 GeV) from the μ.

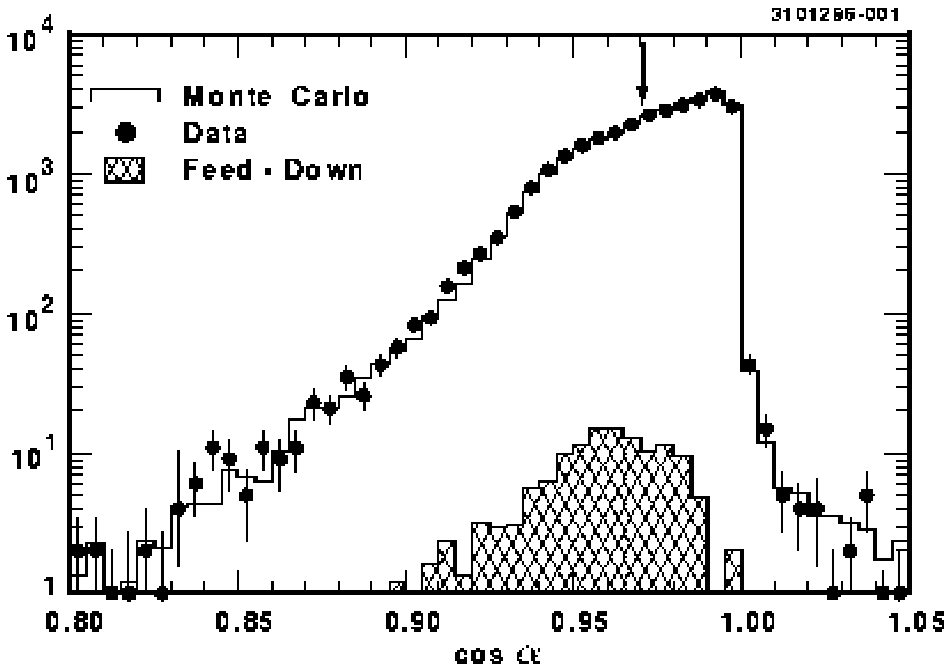

Figure 18. Angular distribution of the lepton in $\tau \to l\nu\nu$. α is the angle between the e or μ motion and the τ motion, estimated using the A motion in the tag, $\tau \to A\nu$.

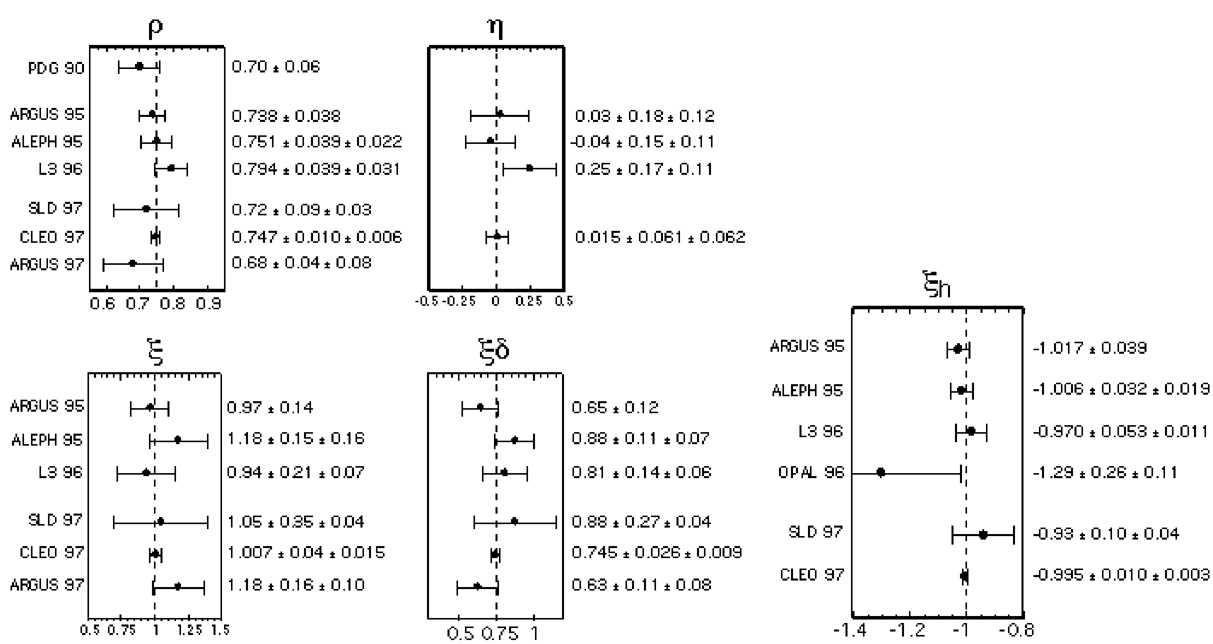

Figure 19. Recent measurements of the Michel parameters in $\tau \to e\nu\nu$ and $\tau \to \mu\nu\nu$. ξ_h is a measure of the neutrino helicity in $\tau \to Ah$. Dashed lines show the standard model predictions.

	μ	τ
ρ	0.7518±0.0026	0.747±0.012
η	-0.007±0.013	-0.015±0.09
δ	0.749±0.004	
ξ		1.00±0.04
$\xi\delta$		0.745±0.03
$\xi \mathbf{P}_\mu$	1.00±0.04	
$\xi_\mathbf{h}$		0.995±0.01

Table 6. Comparison of measurements of Michel parameters in μ and τ decay. Errors are combined statistical and systematic.

Possible Observation of $c\bar{s}$ Annihilation in Hadronic D_s Decay

The leptonic decay $D_s \to \mu\nu$ is important, because it proceeds via an annihilation process (figure 20) and is a measure of the weak decay constant, f_{Ds}. This decay has been difficult to see, because the background is large, and I regard the published measurements[23] to be weak evidence for this process. The inferred decay constants are not consistent with each other, probably indicating serious systematic problems (see table 7). Figure 21 shows the CLEO data. The backgrounds pose serious problems.

It has been suggested that the decay $D_s \to \omega\pi$ could provide independent evidence for the annihilation decay of the D_s. No spectator process contributes to this final state, because the ω contains no s quarks. It is hoped that final state interactions, the bane of charm physics, may not confuse the issue, although this is somewhat controversial. CLEO now has a clear 4.5σ signal for $D_s \to \omega\pi$ (see figure 22) and reports[24] a $(2.7 \pm 1.2) \times 10^{-3}$ branching fraction.

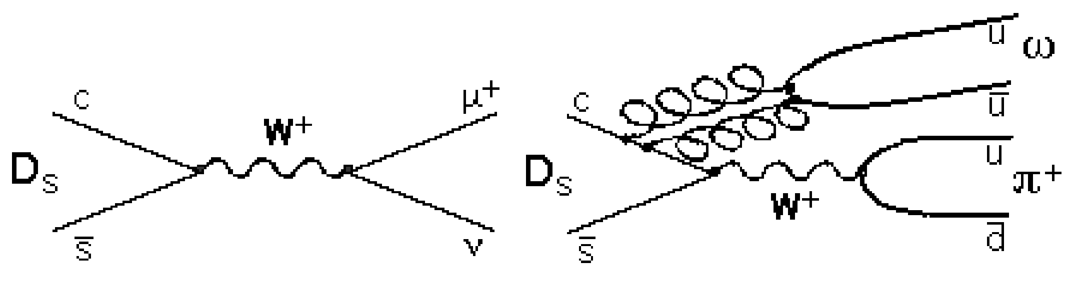

Figure 20. Feynman diagrams for the processes $D_s \to \mu\nu$ and $D_s \to \omega\pi$. The latter does not occur without gluonic corrections.

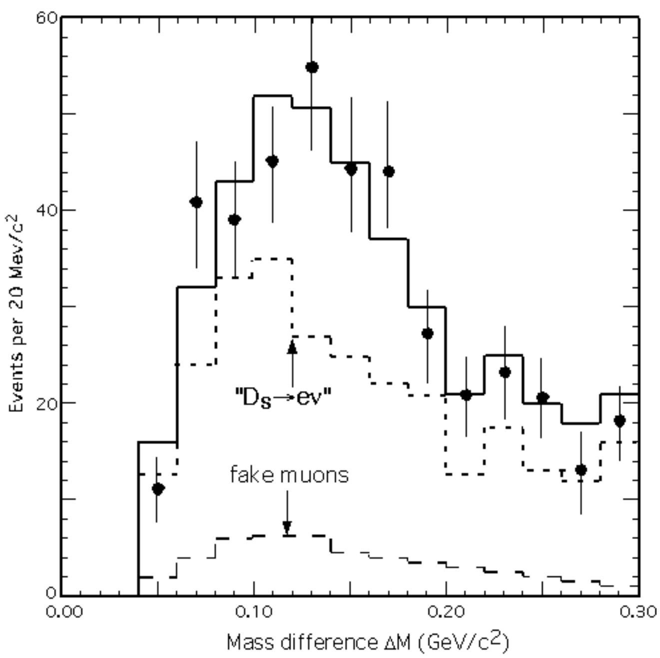

Figure 21. CLEO measurement of $D_s \to \mu\nu$. "Mass difference" means $M(D_s\gamma)$ - $M(D_s)$. "$D_s \to e\nu$" is an estimate of the background.

Experiment	f_{Ds} (MeV)
Fermilab E653	194 ± 35 ± 20 ± 14
CERN WA75	238 ± 47 ± 21 ± 43
CLEO	344 ± 37 ± 52 ± 42
BES	430 ± 140 ± 40
LEP L3 ($D_s \to \tau\nu$)	309 ± 58 ± 33 ± 38

Table 7. Measurements of f_{Ds} using $D_s \to \mu\nu$ (ref. 22). L3 uses $D_s \to \tau\nu$.

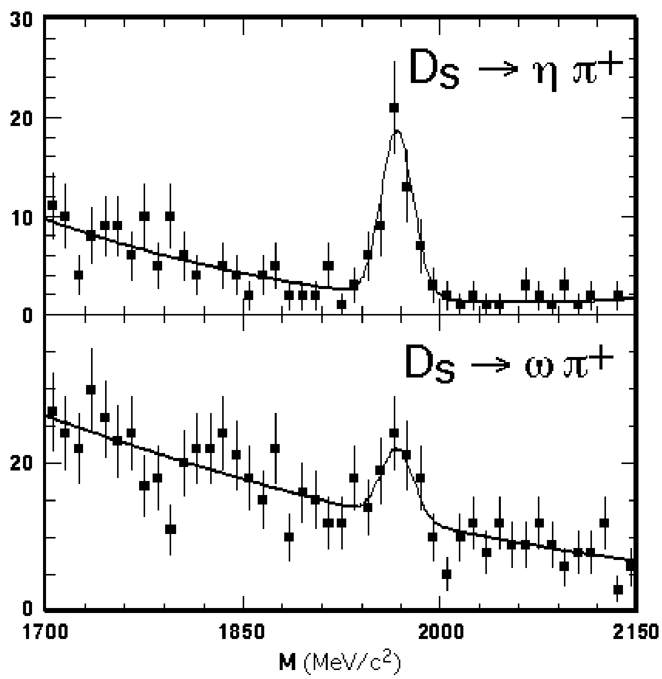

Figure 22. Signal for $D_s \to \omega\pi$, compared with the previously observed $D_s \to \eta\pi$.

Summary

- The "charm deficit" persists as a 2σ problem. No obvious error or solution.
- Factorization tests can now be done on single decay modes. It seems to work.
- Studies of rare hadronic B decays, for "CP engineering," are in progress.
- New methods for V_{cb} verify previous measurements and support HQET.
- Precise measurements of the τ Michel parameters allow the τ to rival the muon in new physics sensitivity.
- Weak annihilation of $c\bar{s}$ into hadrons may have been seen.

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