WEAK DECAY OF HEAVY QUARK MATTER

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ABSTRACT

Recent experimental results on CHARM and BOTTOM decay are presented. The significance of these results and what is needed for a more complete description of heavy quark decay is discussed.

Introduction

The existence of heavy quarks was predicted[1] long before any observation of matter made of heavy quarks. However, the Standard Model has parameters which must be determined by our measuring the properties of heavy quark decay. This paper is a summary of the new results related to the weak decay of D and B mesons gathered during the past year.

Subjects of interest related to CHARM:
A. The Semileptonic Decay $D^+ \rightarrow K^{*0} \ell^+ \nu$
B. Measurement of $D \rightarrow \phi \pi$ Branching Ratio.
C. Rare Decays of $D^0 \rightarrow \phi \pi$ and $D^0 \rightarrow \pi \pi$.
D. Decay of $D^0$ to $K^{*0}, K^0\eta$, and $K^0\eta'$.
E. Status of the Charm Lifetimes and Branching Ratios.

Topics associated with B meson decay:
F. Decay of the $T(4S)$ to non BB States.
G. The Semileptonic Decay of B Mesons to Exclusive Final States.
H. Evidence for $b\tau$ Transitions and an Estimate of $|V_{ub}|/|V_{cb}|$.
I. Update of the $B^0 \rightarrow B^0 \pi$ Mixing.
J. Exclusive Hadronic B Decays.
K. Rare Decays of B Mesons.
L. Status of Measured B Meson Decays.

CHARM DECAY

A. The Semileptonic Decay $D^+ \rightarrow K^{*0} \ell^+ \nu$

The first measurement of the lepton spectrum from semileptonic D decay[2] was described by models in which the $D^+ \rightarrow K^{*0} \ell^+ \nu$ branching fraction was the same as $D^0 \rightarrow K^0 \ell^+ \nu$. At that time some of us wondered why the semileptonic branching fraction ratio to these final states, i.e. the vector to pseudoscalar ratio, was 1 rather than 3, which would be the prediction based on the number of final states. The equal vector to pseudoscalar ratio was approximately confirmed by MARK III in 1985[3]. At the 1988 Munich Conference, the E691 experimental collaboration presented results for both branching fractions,

\[ Br(D^+ \rightarrow K^{*0} e^+ \nu) = (4.9 \pm 0.5 \pm 0.9)\% \]
\[ Br(D^+ \rightarrow K^0 e^+ \nu) = (9.8 \pm 1.3 \pm 1.5)\% \]

During the past year interest in the $D^+ \rightarrow K^{*0} \ell^+ \nu$ branching fraction has been renewed because of attempts to measure the $D_s \rightarrow \phi \pi$ branching fraction, which is discussed in the next section. The E691, ARGUS, and CLEO collaborations have come out with new values which essentially confirms the 1988 branching.
The new results for the branching ratio, \( Br(D^+ \rightarrow K^0 e^+ \nu) \), are listed below:

\[
\begin{align*}
(4.5 \pm 0.7 \pm 0.5)\% & , \quad \text{E691 [4]} \\
(5.0 \pm 0.7 \pm 1.2)\% & , \quad \text{ARGUS [5]} \\
(3.8 \pm 1.0 \pm 1.0)\% & , \quad \text{CLEO 6[1]} \\
\end{align*}
\]

\[(4.4 \pm 0.5 \pm 0.6)\% \quad \text{Average}\]

The Vector/Pseudoscalar problem has been enhanced to a ratio of 0.5 rather than 3. However, we can always explain this ratio using form factors. There is one form factor associated with the decay to \( K\ell\nu \) and three required to describe the decay to \( K^0\ell\nu \). The challenge is to pin down these form factors. The form factors associated with the \( K^* \) decay determine its polarization, and efforts have started to measure this. Preliminary results from E691[7] are \( A_1(0) = 0.46\pm0.05\pm0.05, \) \( A_2(0) = 0.0\pm0.2\pm0.1, \) \( V(0) = 0.9\pm0.3\pm0.1 \) for the two axial vector and vector form factors. The ratio of the longitudinal to transverse polarization of the \( K^0 \) meson is \( 1.8\pm0.6\pm0.3 \). The results are in serious disagreement with theoretical predictions[8]. E653 has started extracting the same form factors from their data sample. They have preliminary values, which are not completely consistent with the E691 result (Longitudinal to Transverse Polarization ratio = 1.1\pm0.3)[9]. They also presented a preliminary value for the vector to pseudoscalar ratio of \( (D^0 K^0\ell\nu)/(D^+ K \ell \nu) = 0.8\pm0.2 \). Since this subject is crucial for checking theoretical models, we must have independent experimental measurements of the associated form factors.

B. The \( D_S^+ \rightarrow \phi \nu \) Branching Ratio

The first evidence for the \( D_S \) meson at a mass of 1.970 GeV/c\(^2\) was observed through reconstructing its decay to \( \phi \nu \). To determine its branching fraction, one needed to know how many \( D_S \) mesons were in the data sample. There was no way to determine this empirically, and the branching fraction was calculated by assuming the total \( e^+e^- \) cross section to CHARM is \( 4\times3 \sigma(e^+e^-\mu^+\mu^-) \) and estimating the \( D_S \) production cross section by subtracting off the cross sections \( \sigma(e^+e^-\phi\ell\nu) \) and \( \sigma(e^+e^-\text{charmed baryons}) \). This led to \( Br(D_S^+\phi\nu) = (2\pm1)\% \). Since then, the \( D_S \) meson has been observed through many decay modes, but the branching fractions have only been determined relative to \( D_S^+\phi\nu \). The recent Particle Data Group estimate of the \( D_S^+\phi\nu \) branching fraction using the same technique just described is \( (2.7\pm0.7)\%[10] \).

The \( D_S \) lifetime has been measured[PDG(90)]. In principle a theoretical calculation of the partial width to any observed mode combined with the lifetime would provide the branching fraction to that decay mode. Then the branching fractions of all other observed modes would be empirically fixed. Unfortunately, the uncertainty in the theoretical calculations have been so large that this scheme was not considered practical.

\[
\begin{align*}
D_S & \rightarrow \phi \nu \\
D_S & \rightarrow K^0 \ell \nu \\
D_S & \rightarrow K^0 \ell \nu \\
\end{align*}
\]

\[\text{Fig. 1 Quark Diagrams for Semileptonic } D \quad \text{and } D_S \text{ decay to vector meson}\]

It has been suggested that the semileptonic decay of the \( D_S \) meson to \( \phi\ell\nu \) should be analogous to the decay of \( D \) to \( K^0\ell\nu \). The spectator diagrams shown in Fig. 1 certainly appear identical. Wirbel et al.[11] estimated the ratio of partial widths from form factors and phase space to be \( 0.83 \), and Isgur et al.[12] estimated the ratio to be \( 0.78 \). Taking the average of these ratios as \( f_f = 0.80 \pm 0.08 \), we can write
\[ \Gamma(D_s + \phi \ell \nu) = f_s \Gamma(D^+ + K^*0\ell^+\nu) \]

and use this to calculate \( \Gamma(D_s + \phi \ell \nu) \) from the measured branching fraction, \( \text{Br}(D^+ + K^*0\ell^+\nu) \), and the \( D^+ \) lifetime. Since the \( D_s \) lifetime is known, the \( D_s + \phi \ell \nu \) branching fraction can be calculated from:

\[ \text{Br}(D_s + \phi \ell \nu) = f_s \frac{\tau(D_s)}{\tau(D^+)} \text{Br}(D^+ + K^*0\ell^+\nu) \]

From the lifetimes listed in the PDG(90) and the average \( D^+ + K^*0\ell^+\nu \) branching ratio given above, one obtains,

\[ \text{Br}(D_s + \phi \ell \nu) = (1.5 \pm 0.3)\% \]

Recently there have been attempts by E691[4], CLEO[6], and ARGUS[5] to observe the decay \( D_s + \phi \pi \) in order to measure the branching fraction of \( D_s + \phi \pi \) relative to \( D_s + \phi \ell \nu \). In particular, by reconstructing \( N(D_s + \phi \ell \nu) \) events and \( N(D_s + \phi \pi) \) events in the same data sample, one is able to calculate the branching fraction ratio from

\[ \frac{\text{Br}(D_s + \phi \pi)}{\text{Br}(D_s + \phi \ell \nu)} = \frac{N(D_s + \phi \pi)}{N(D_s + \phi \ell \nu)} / \epsilon_{\phi \pi} / \epsilon_{\phi \ell \nu}, \]

where \( \epsilon_{\phi \pi}, \epsilon_{\phi \ell \nu} \) are the relative efficiencies for reconstructing the events. The results of the experiments are shown in Table I.

Table I, Results on \( \text{Br}(D_s + \phi \pi) \) from Observation of \( D_s + \phi \ell \nu \)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>( N_{\phi \ell \nu} )</th>
<th>( N_{\phi \pi} )</th>
<th>( \text{Br}(D_s + \phi \pi) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>E691</td>
<td>&lt; 7.8</td>
<td>8900±1400</td>
<td>&gt; 3.4% (3.1±1.3)% (3.0±1.2)%</td>
</tr>
<tr>
<td>CLEO</td>
<td>54 *11</td>
<td>400 *27</td>
<td></td>
</tr>
<tr>
<td>ARGUS</td>
<td>104 *26</td>
<td>???????</td>
<td></td>
</tr>
</tbody>
</table>

E691 has the largest sample of \( D_s + \phi \pi \) events. However, identifying a \( \phi \ell \nu \) final state is challenging and they were unable to demonstrate its existence in their data sample. Hence they obtain a lower limit on the \( D_s + \phi \pi \) branching ratio. CLEO and ARGUS were able to "reconstruct" \( D_s + \phi \ell \nu \) events and ended up with the same \( D_s + \phi \pi \) branching ratio.

Using the value in Table I to normalize the branching ratios of all other observed \( D_s \) final states, which are shown in Table II, leads to the conclusion that we have tabulated approximately half of the \( D_s \) final states. It has been suggested[13] that the decay modes \( \eta' \pi^+ \pi^0 \) and \( D_s + \eta' \pi^+ \pi^- \) could constitute an additional 24% and hence our understanding of \( D_s \) decay is at the 70% level which is comparable with tabulation of \( D^0 \) decays. However, we need experimental confirmation of most values listed in Table II before believing that \( D_s \) decay is in the same state as the \( D \) mesons.

Table II, Renormalized \( D_s \) Branching Ratios

<table>
<thead>
<tr>
<th>DECAY MODE</th>
<th>BRANCHING FRACTION (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi \pi^+ )</td>
<td>3.1 ± 0.9</td>
</tr>
<tr>
<td>( \phi \pi^+ \pi^0 )</td>
<td>7.4 ± 4.0</td>
</tr>
<tr>
<td>( \phi \pi^+ \pi^- )</td>
<td>1.5 ± 0.7</td>
</tr>
<tr>
<td>( \bar{K}^0K^+ )</td>
<td>3.0 ± 0.9</td>
</tr>
<tr>
<td>( K^0\bar{K}^+ )</td>
<td>3.0 ± 0.8</td>
</tr>
<tr>
<td>( \eta' \pi^0 )</td>
<td>8.0 ± 2.9</td>
</tr>
<tr>
<td>( \pi^+ \pi^- )</td>
<td>1.4 ± 0.5</td>
</tr>
<tr>
<td>( X\ell^\nu )</td>
<td>2(7.7 ± 1.2)</td>
</tr>
</tbody>
</table>

Total 46.5 ± 5.9

\( \phi \pi^+ \); Fraction comes from Table I.
\( \eta' \pi^0 \); A new result from ARGUS[14]
\( X\ell^\nu \); My Guess: \( \text{Br}_{s1}(D_s) = \text{Br}_{s1}(D^0) \)
Rest are scaled from PDG(90) values.

C. The Rare Decay of \( D^0 \) to \( \bar{K}K \) and \( \pi\pi \)

The Cabibbo suppressed decay of \( D^0 + K^+K^- \) and \( D^0 + \pi^+\pi^- \) are described in the Electroweak
The same KMC matrix elements are involved in each final state. Combination of phase space and the elementary matrix elements leads one to expect \( \text{Br}(D^0 \rightarrow K^+K^-) < \text{Br}(D^0 \rightarrow \pi^+\pi^-) \). The PDG(1990) value for \( D^0 \rightarrow K^+K^- \) is significantly higher than \( D^0 \rightarrow \pi^+\pi^- \). The branching ratios recently measured by ARGUS and CLEO[15] are listed in Table III.

The new measurements yield a smaller ratio but confirm that \( \Gamma(D^0 \rightarrow K^+K^-) \) is higher than \( \Gamma(D^0 \rightarrow \pi^+\pi^-) \). Since this result is in contradiction to the Quark Diagram calculation, it becomes a strong support for using Final State Interactions to describe some D meson decays.

The quark diagrams describing the decay of \( D^0 \rightarrow K^0K^0 \) and \( D^0 \rightarrow \pi^0\pi^0 \) are shown in Fig. 3. The two diagrams leading to \( K^0K^0 \) have opposite sign amplitudes and hence cancel[17].

![Fig. 3, Quark Diagrams of D^0 decay to K^0K^0 and to \pi^0\pi^0](image)

Therefore, we might expect to see only the \( \pi^0\pi^0 \) decay mode. The \( D^0 \) decay to \( K^0K^0 \) was observed by experiment E400[18]. This year CLEO measured the \( K^0K^0 \) branching fraction to be \( \text{Br}(D^0 \rightarrow K^0K^0) = (0.13 \pm 0.07)\% \), and set an upper limit of 0.46\% (90\% confidence level) on the \( \pi^0\pi^0 \) branching fraction. On the other hand, ARGUS[15] has found no evidence for \( K^0K^0 \) and set an upper limit of 0.11\% (90\% CL). Since evidence for \( D^0\pi^0\pi^0 \) has not been observed, some believe one should not "postulate" W exchange diagrams to describe weak decays. However, since the current upper limit is only 0.46\%, it is necessary to reduce this limit an order of magnitude before making such a statement.

![Fig. 2, Diagrams for D^0 K^+ K^- and D^0 \pi^+ \pi^-](image)

Table III, \( D^0K^+K^- \) and \( D^0\pi^+\pi^- \) Branching Ratios, (%)

<table>
<thead>
<tr>
<th></th>
<th>PDG(1990)</th>
<th>CLEO</th>
<th>ARGUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Br}(D^0\rightarrow K^+K^-) )</td>
<td>0.45 \pm 0.07</td>
<td>0.49 \pm 0.08</td>
<td>0.42 \pm 0.08</td>
</tr>
<tr>
<td>( \text{Br}(D^0\rightarrow \pi^+\pi^-) )</td>
<td>0.11 \pm 0.03</td>
<td>0.21 \pm 0.05</td>
<td>0.17 \pm 0.04</td>
</tr>
<tr>
<td>( \text{Br}(D^0\rightarrow K^0K^0) / \text{Br}(D^0\rightarrow \pi^+\pi^-) )</td>
<td>4.09 \pm 1.28</td>
<td>2.35 \pm 0.46</td>
<td>2.5 \pm 0.7</td>
</tr>
</tbody>
</table>

The individual branching fractions of CLEO and ARGUS have been normalized with the \( D^0K^- \pi^+ \) branching ratio, \( \text{Br}(D^0\rightarrow K^-\pi^+) = (4.2\times 0.4\times 0.4)\%[16] \), rather than the PDG(90) value of (3.71\times 0.25)\%. 

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D. Decay of $D^0$ to $K^0\pi^0$, $K^0\eta$, and $K^0\eta'$

The $D^0$ decay to $K^0\pi^0$, $K^0\eta$, and $K^0\eta'$ can be described by the color suppressed diagram and by the $W$ exchange diagrams shown in Fig. 4.

Color Suppressed Diagram,

\[
\begin{array}{c}
\text{c} \\
\text{s} \\
\text{d} \\
\text{u} \\
\end{array}
\begin{array}{c}
\text{D}^0 \\
\rightarrow \\
\xi',\eta,\eta' \\
\end{array}
\]

W Exchange Diagrams,

\[
\begin{array}{c}
\text{c} \\
\text{s} \\
\text{d} \\
\text{u} \\
\end{array}
\begin{array}{c}
\text{K}^0 \\
\rightarrow \\
\xi',\eta,\eta' \\
\end{array}
\begin{array}{c}
\text{c} \\
\text{s} \\
\text{d} \\
\text{u} \\
\end{array}
\begin{array}{c}
\rightarrow \\
\xi',\eta,\eta' \\
\end{array}
\]

\begin{figure}
\caption{Quark Diagrams of $D^0 + K^0\pi^0$, $K^0\eta$, $K^0\eta'$}
\end{figure}

According to SU(3) symmetry, (i.e. the Octet-Singlet Quark Model), the color suppressed diagram produces\[19\],

\[
\frac{\Gamma(K^0\pi^0)}{\Gamma(K^0\eta)} = \frac{\Gamma(K^0\eta')}{\Gamma(K^0\eta)} = 2.
\]

The $W$ exchange diagrams interfere destructively for $\eta$, and constructively for $\eta'$ final states. Hence one expects

\[
\frac{\Gamma(K^0\eta)}{\Gamma(K^0\eta')} > \frac{\Gamma(K^0\eta)}{\Gamma(K^0\eta')}
\]

The three decay modes have been measured by the ARGUS and MARK III collaborations\[20\]. Their results are given in Table IV.

Table IV, Branching Ratio for $D^0 + K^0\pi^0$, $K^0\eta$, and $K^0\eta'$

<table>
<thead>
<tr>
<th>MODE</th>
<th>ARGUS</th>
<th>MARK III</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^0\pi^0$</td>
<td>1.7±0.4±0.3</td>
<td>1.8±0.2±0.2</td>
</tr>
<tr>
<td>$K^0\eta$</td>
<td>1.4±0.5±0.3</td>
<td>1.6±0.6±0.4</td>
</tr>
<tr>
<td>$K^0\eta'$</td>
<td>1.9±0.4±0.3</td>
<td>3.3±0.3±1.0</td>
</tr>
</tbody>
</table>

MARK III observes a large enhancement of the $K^0\eta'$ mode. Averaging the ARGUS and MARK III results and factoring out the phase space contributions yields the ratio of matrix elements,

\[
\frac{|A(D^0+K^0\eta')|^2}{|A(D^0+K^0\eta)|^2} = 2.5 ± 0.7.
\]

The fact that this number is greater than unity is an indication that exchange diagrams may be needed to describe $D$ meson decay.

B. Status of the CHARM Lifetimes and Branching Ratios

The lifetimes (units of $10^{-13}$ sec) of the $D^0(\tau=4.21±0.1), D^+(\tau=10.6±0.3), D_s(\tau=4.48±0.35)$ mesons, and $\Lambda_c(\tau=1.94±0.17)$ have been measured\[21\]. Since the connection between theoretical calculations and measured branching fractions are made via lifetime measurements, they are important. E691 demonstrated that fixed target experiments can provide much more precise results than the $e^+e^-$ storage rings. There are now many new fixed target experiments starting to collect data, and they may be able to further improve the measured lifetimes. E687\[22\] submitted preliminary results for the $D_s$ and $\Lambda_c$ lifetime; $\tau(D_s) = (0.5±0.06±0.03)$, $\tau(\Lambda_c) = (0.2±0.03±0.03)$ psec. These results are consistent with the values above, but lead one to recognize that $D_s$ and $\Lambda_c$ lifetimes are currently only known at the 10% level.

As discussed in section B, a large amount of information on $D^0$ and $D^+$ meson branching ratios has been accumulated. According to PDG(1990), we have exclusive branching fractions for approximately 65% of the $D^0$ and 45% of the $D^+$ mesons. The absolute scaling of all of the numbers is based on the MARK III branching fractions. These were derived
by single meson and dual meson reconstruction of $e^+e^- \to D^+D^-$ (or $D^{+0}$) mesons. The number of single meson reconstructions to a given final state determines the branching fraction times production cross section. The ratio of dual meson reconstruction to single meson reconstruction is used to determine the absolute branching ratio. This technique is the most reliable way to determine absolute branching ratios. Unfortunately, the MARK III collaboration was statistically limited and our understanding of these branching fractions is limited at the 10% level. The ACCMOR collaboration has used the same type of analysis, comparing single and double CHARM reconstruction, to extract absolute branching fractions[23]. The technique is much more difficult in a fixed target experiment because the final state is usually not exclusive DD. However, they have demonstrated that the technique could allow independent measurements of some absolute branching fractions with fixed target experiments. The preliminary version of their paper indicates the importance of including photon detectors in future fixed target experiments, to allow reconstruction of final states containing $K^0_S$. However, these fixed target experiments are based on their ability to isolate the D meson decay vertex, but there is no way to establish which vertex a photon came from. Probably the improved measurement of absolute branching fractions will be done at BEPC.

**BOTTOM DECAY**

**F. Decay of $T(4S)$ to Non $B\bar{B}$ States**

Except for measurements of the lifetime of matter containing $b$ quarks, the properties of $B$ meson decay have been limited to studying the $T(4S)$ decaying to $B\bar{B}$. Until now, we have always assumed the $T(4S)$ decays exclusively to $B^+B^-$ or $B^{-0}B^0$. If the $T(4S)$ resonance decays to a $B\bar{B}$ state, the particles coming from the $B$ decay are limited to a maximum momentum of 2.7 GeV/c. A $\psi$ meson coming from the $B$ meson decay at the $T(4S)$ has a momentum less than 1.97 GeV/c. CLEO[24] has seen $\psi$ from the $T(4S)$ with momentum greater than 2 GeV/c. In Fig. 5, the inclusive momentum spectrum of $\psi$ mesons coming from the $T(4S)$ is shown. Below 2 GeV/c there is a large signal from the $B$ meson decays. However, there is also a significant signal between 2 and 5 GeV/c. For $p_\psi > 1.97$ GeV/c, the inclusive branching fraction is

$$Br(T(4S) \to \psi X) = (0.22 \times 0.06 \times 0.04)\%.$$
The CLEO publication has created interest amongst theorists concerned with B meson decay[26] At this time there is no further information on what fraction of the T(4S) decays are not to BB. All previously published branching fractions on B decays at the T(4S) are based on the assumption that the T(4S) decays exclusively to BB. There are several problems that are difficult to explain. One of them has to do with the inclusive semileptonic branching fraction for B mesons which has been measured by ARGUS and CLEO to be (10.2 ± 0.3)%. Measurements at PEP and PETRA (i.e., not at the T(4S)) yielded (12.2 ± 0.9)%. At the conference, the L3 Collaboration reported a new measurement which yielded (11.6 ± 0.4 ± 0.4)%%. The elementary quark model theory predicts the branching fraction to be approximately 16%. Supposedly, "QCD Corrections" are able to lower the fraction to 12%, but I have been told that it is very difficult to explain a value less than 12%. If the T(4S) decays to BB only 80% of the time, the branching fractions obtained at ARGUS and CLEO would be raised to 12.2%.

To extract exclusive B meson branching fractions from existing data at the T(4S), one must know the absolute branching ratio of T(4S) to B^+B^- (We refer to this as f_{++-}), and to B^0B^0 (Designated f_{oo} through the rest of this paper.). Until now, these branching fractions have been estimated on the basis of the B^0 - B^+ mass difference and a range of theoretical suggestions. The sum f_{oo} + f_{++-} has always been set to unity, and the range of values for f_{oo} has varied from 0.4 to 0.5. Recently, several theorists[28] have calculated "electromagnetic corrections" to the T(4S)→B^0B^0 and T(4S)→B^+B^- branching fractions. The uncertainties in the electromagnetic corrections are of order 5% depending on what one uses for quark wave functions or form factors. The best solution to this problem requires measurement of f_{oo} and f_{++-} to an accuracy of at least 5%. In principle this can be done by tagging or complete event reconstruction at the T(4S), a very challenging project. For the rest of this paper, I assume the branching fraction of the T(4S) to BB is greater than 0.997, and the individual branching ratios are equal, i.e. f_{oo} = f_{++-} = 0.50.

G. The Semileptonic Decay of B Mesons to Exclusive Final States

Study of the semileptonic decay of B mesons is a powerful method for fixing the basic parameters of the Electroweak Model which are needed for describing the decay process. The B meson decays almost exclusively to D mesons, and hence the expected exclusive final states are B → D^0ν, D^+ν, B^{**}ν, and the non resonant D(nπ)νν. Full reconstruction of the final state is impossible because of the neutrinos, and hence one must use the detected particles and calculate the missing mass.

\[ M^2 = (E_{B^-} - (E_{\bar{D}} + E_D))^2 - (p_{B^-} - p_{\bar{D}})^2 \]

Lack of knowledge of the direction of the B meson requires one to set the B momentum to zero, which increases the uncertainty in the missing mass spectrum. Although the B meson is almost at rest, this broadens the width of the missing mass peak to ±0.5 GeV/c. In Fig. 6, a D^± missing mass spectrum is shown after the subtraction of backgrounds. One sees an asymmetric peak at zero missing mass. The asymmetry comes from the fact that this is a D^± missing mass spectrum, but some of the events are B^→D^±ν follow by D^→πD or γD. These produce positive missing mass squared. The exclusive branching fractions B^→D^±ν and B^→D^±νν can be determined by fitting the
Fig. 6 Missing mass squared spectrum from CLEO data with fit[30]; (a) D°£, (b) D＊£. Backgrounds have been subtracted. The three fit components are: solid_D°£; dashed_D＊£; dotted_D＊ or non-resonant D(nπ)£.

measured spectrum to a theoretical model. Results from ARGUS[29] and CLEO[30] are listed in Table V. According to the CLEO results, the D£ and D£ν final states account for (64±10±8)% of the semileptonic B meson decays. Since ARGUS has only provided the B° branching ratios, there is an additional uncertainty in the fraction of semileptonic decays to these states. However, using 10% for the inclusive branching ratio, ARGUS would obtain (78±12±15)% of the B° semileptonic decays are

into these two decay modes. Theoretical estimates of Isgur et al.[12] expected 80%. These exclusive branching fractions provide a measure of the Vector to Pseudoscalar Ratio, which are also given in Table V. The average of CLEO and ARGUS is 2.9±1.6, a result which is independent of f° and f°+. Apparently for B mesons, unlike D meson, the ratio is close to phase space (i.e., the number of states).

Table V, Exclusive Branching Ratios from Semileptonic B Decay

<table>
<thead>
<tr>
<th>Final State</th>
<th>CLEO[30]</th>
<th>ARGUS[29]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(%)</td>
<td>(%)</td>
<td></td>
</tr>
<tr>
<td>B°→ D°£ν</td>
<td>1.8±0.6±0.3</td>
<td>1.8±0.6±0.5</td>
</tr>
<tr>
<td>B°→ D＊£ν</td>
<td>4.6±0.5±0.7</td>
<td>6.0±1.0±1.4</td>
</tr>
<tr>
<td>B→ D°£ν</td>
<td>1.6±0.6±0.3</td>
<td></td>
</tr>
<tr>
<td>B→ D＊£ν</td>
<td>4.1±0.8±0.9</td>
<td></td>
</tr>
</tbody>
</table>

| Vector      | 2.6±1.5        |
| Pseudoscalar| 3.3±1.1        |

Isospin symmetry requires \( \Gamma(B°→D°£ν) = \Gamma(B^+→D£ν) \), and therefore one can use the exclusive branching ratios to calculate the lifetime ratios. Using the CLEO numbers shown in Table V one obtains,

\[
\frac{\tau}{\tau} = \frac{Br(B°→D°£ν)}{Br(B^+→D£ν)} = 0.89±0.19±0.13 \frac{f°}{f°+}
\]

One should note, since the B° (B+) branching fractions are inversely proportional to what one assumes for \( f° \) and \( f°+ \), the lifetime ratios depend on the \( f°/f°+ \) ratio.

ARGUS[31] derived the lifetime ratio from the yields of D°, D+, and D＊ in semileptonic decays, in order to make better statistical use of their data. Their result is

\[
\frac{\tau}{\tau} = 1.00±0.23±0.14 \frac{f°}{f°+}
\]
Theoretical models provide partial decay rates in terms of the KNO matrix elements. The exclusive semileptonic decay rate to a pseudoscalar meson is supposed to be the most reliably calculated. Given the B meson measured lifetime and the exclusive branching fraction to $D\ell\nu$, one can calculate $|V_{cb}|$. However, the measured lifetime is an average over $B^0$, $B^+$, $B_s$, and baryons containing a $b$ quark. Therefore to extract a value for $|V_{cb}|$ from the exclusive semileptonic branching ratio, we assume

$$\tau_{B^0} = \tau_{B^+} = (1.16 \pm 0.14) \times 10^{-12} \text{ sec},$$

and then combine this with the $B^0+D\ell\nu$ branching fraction to obtain the partial width,

$$\Gamma(B^0+D\ell\nu) = (1.55 \pm 0.50) \times 10^{-10} \text{ sec}^{-1}.$$

In Table VI, the values of $|V_{cb}|$ derived from three different theoretical models are listed. For comparison, we also give the predicted vector to pseudoscalar ratio for each model.

Table VI, $|V_{cb}|$ Calculated from Different Models of $\Gamma(B^0+D\ell\nu)$

| MODEL     | $\Gamma(B^0+D\ell\nu)$ / $\Gamma(B^0+D\ell\nu)$ | $\Gamma(B^0+D\ell\nu)$ / $\Gamma(B^++D\ell\nu)$ | $|V_{cb}|$ |
|-----------|-----------------------------------------------|-----------------------------------------------|-----------|
| ISGW[12]  | 2.3                                           | 11.2$|V_{cb}|^2$                                  | 0.037±0.005|
| KS[32]    | 3.1                                           | 8.3$|V_{cb}|^2$                                  | 0.043±0.007|
| WBS[33]   | 2.7                                           | 8.1$|V_{cb}|^2$                                  | 0.044±0.007|
| Average   | 2.7                                           | 9.2$|V_{cb}|^2$                                  | 0.041±0.007|

H. Evidence for $b\bar{u}$ Transitions and an Estimate of $|V_{ub}|/|V_{cb}|$

At the 1989 Photon Lepton Conference, preliminary presentations were made of evidence for $b\bar{u}$ transitions. Both ARGUS[34] and CLEO[35] have since published results. For semileptonic decay of $B$ to $D\ell\nu$, the lepton momentum is limited to 2.4 GeV/c. (Here we are describing $B$ mesons coming from the $\Upsilon(4S)$, where their momentum is 0.325 GeV/c, i.e. almost at rest.) On the other hand, for $B^+ \pi$ (or $\rho$, or $A_1$) $\ell\nu$, the lepton momentum spectrum extends to 2.6 GeV/c. The CLEO lepton momentum distribution with a fit to theoretical spectra is shown in Fig. 7.

![Fig. 7 Lepton momentum distribution from CLEO data with fit using $b\bar{u}\ell\nu$ spectrum and the cascade spectrum.](image)

The $b\bar{u}\ell\nu$ spectrum was generated from measurement of the $D$ meson momentum distribution and folding it with a theoretical spectrum for semileptonic charm decay. The $b\bar{u}\ell\nu$ spectrum is displayed for illustration purposes only. The high momentum region of the lepton spectrum measured by ARGUS is shown in Fig. 8. They have subtracted the continuum contribution, which extends to 4.5 GeV/c. The solid histogram is a theoretical $b\bar{c}\ell\nu$ spectrum which they normalized to their data between 2 and 2.3 GeV/c. One notices a statistically
The lepton momentum spectrum of the ISGW model has a softer endpoint and hence leads to a larger value of $|V_{ub}|$. Currently there is no way to choose between the models. The average over all of them gives $|V_{ub}|/|V_{cb}| = 0.12 \pm 0.03$.

After publication of the Non-$B\overline{B}$ decay of the $\Upsilon(4S)$, many persons suggested that the lepton signal above 2.4 $\text{GeV}/c$ may not come from $B$ meson decay. For example, the $\Upsilon(4S)$ could decay to $D\overline{D}X$ and the $D$ decay semileptonically. Both CLEO and ARGUS have looked for evidence of $D$ mesons of momentum greater than 2.5 $\text{GeV}/c$ coming from the $\Upsilon(4S)$ and have seen nothing. Furthermore, it requires a clever mechanism to have the lepton momentum spectrum end at 2.6 $\text{GeV}/c$ as shown in Fig. 8. In addition to these two arguments in support of the evidence for $b+u$, ARGUS[37] has reconstructed two complete events in which one of the $B$ mesons decays to a non-charm final state. In one case a $\overline{B}^0$ decays to $\pi^+\mu^-\nu$, and in the other $B^+$ decays to $\omega^0\mu^-\nu$. The reconstructed $\Upsilon(4S)\to B^0\overline{B}^0$ decay is shown in Fig. 9. The missing mass of the semileptonic decay is calculated much more precisely in this event than those shown in Fig. 6, because they are able to calculate the direction of the $B$ meson from the fully reconstructed hadronic decay of the other $B$ meson. Although one can postulate other explanations for these two events, they provide strong confirmation of the $b+u$ signal. However, to measure $|V_{ub}/V_{cb}|$ better, one will have to reconstruct a large number of semileptonic decays.

Table VII, $|V_{ub}/V_{cb}|$ from the Semileptonic Decay of $B$ mesons

<table>
<thead>
<tr>
<th>Model</th>
<th>ARGUS ($p_{l} &gt; 2.3$)</th>
<th>CL$E0$ ($p_{l} &gt; 2.2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISGW[12]</td>
<td>0.18 $\pm$ 0.02</td>
<td>0.15 $\pm$ 0.02</td>
</tr>
<tr>
<td>WBS[33]</td>
<td>0.09 $\pm$ 0.01</td>
<td>0.11 $\pm$ 0.02</td>
</tr>
<tr>
<td>ACM[36]</td>
<td>0.10 $\pm$ 0.01</td>
<td>0.09 $\pm$ 0.01</td>
</tr>
<tr>
<td>KS[32]</td>
<td>********</td>
<td>0.09 $\pm$ 0.01</td>
</tr>
</tbody>
</table>
Fig. 9 A complete event reconstruction at the 
T(4S) in which the $B^0$ transforms to $B^0$
before decaying. One $B^0$ decays
hadronically to $D^*+\rho^-$, and the other
decays semileptonically to $\tau^+\nu$.

I. Update of the $B^0 \leftrightarrow \bar{B}^0$ Mixing

$B^0\bar{B}^0$ mixing has been established [38].
During the past year, ARGUS analyzed 70% more
data and confirmed their previous result[39].
Mixing is usually parametrized by the ratio,

$$ r = \frac{\text{Probability}(B^0 + \bar{B}^0 \rightarrow \text{Decay})}{1 - \text{Probability}(B^0 + \bar{B}^0 \rightarrow \text{Decay})} $$

The easiest way to distinguish $B^0$ from $\bar{B}^0$ at
the time of the decay is the sign of the
lepton in the semileptonic decay. $\bar{B}^0$ decays
to $X\ell^-\nu$, whereas $B^0$ decays to $X\ell^+\nu$. At the
T(4S), where one starts with $B^0\bar{B}^0$ in a $C=-1$
state, $r$ can be measured from the number of
like sign dilepton events compared to the
number of unlike sign[40]. If there were
only $B^0\bar{B}^0$ events then,

$$ r = \frac{N(\ell^+\ell^-) + N(\ell^-\ell^+)}{N(\ell^+\ell^-)}. $$

However, the T(4S) also decays to $B^+B^-$ which
contributes to the unlike sign dilepton
sample. Defining $\Lambda^+_{--}$ as the fraction of
dilepton events coming from $B^+B^-$ decay, one
calculates $r$ from the dilepton sample with

$$ r = \frac{N(\ell^+\ell^-) + N(\ell^-\ell^+)}{N(\ell^+\ell^-) - \Lambda^+_{--}(N(\ell^+\ell^-) + N(\ell^-\ell^+) + N(\ell^+\ell^-))}. $$

$\Lambda^+_{--}$ is related to the $B^0$ semileptonic
branching fraction, $b_0 = Br(B^0 \rightarrow X\ell^+\nu)$, the $B^+$
semileptonic branching fraction, $b_+$, and the
T(4S) branching fractions, $f_0^+ f_{++}$.

$$ \Lambda^+_{--} = \frac{f_+ b_+^2}{f_+ b_+^2 + f_0^+ b_0^2}. $$

Currently, from the information already given
about the branching fractions, our favorite
guess is $\Lambda^+_{--} = 0.5$. The value previously
used by ARGUS and CLEO was 0.55. After
background subtractions, ARGUS now has
34.7±10.2 like sign and 381.4±23.3 unlike
dilepton events. This leads to $r = 0.20\pm0.06\pm0.05$, which can be compared with
CLEO's value of 0.17±0.05±0.05 (This has been
corrected for the change in $\Lambda^+_{--}$). The
mixing parameter is related to the mass
difference, $\Delta M$, between $B^0$ eigenstates and
the total decay width, $\Gamma$,

$$ r = \frac{(\Delta M/\Gamma)^2}{2 + (\Delta M/\Gamma)^2}. $$
Using $r = 0.19 \times 0.05$, one obtains $\Delta M / \Gamma = 0.67 \times 0.11$. The mass difference is calculated from the box diagram of the electroweak model[41].

$$\Delta M = \left( \frac{G_F^2}{8\pi^2} \right) (B_{B^+B^0}) m_b |V_{tb} V_{td}|^2 e^2 (m_c / M_W)$$

The unknown parameters are the KMC elements $|V_{tb} V_{td}|$, the QCD correction $\eta$, the B meson structure constant $(B_{B^+B^0})$, and the mass of the top quark $m_t$. There have been theoretical estimates of the first three of these, and used with the measured $\Delta M / \Gamma$ to estimate the mass of the top quark. However, at this stage, the uncertainties in $|V_{tb} V_{td}|$ and $(B_{B^+B^0})$ are too large to make the measurement of $\Delta M / \Gamma$ a practical constraint on the top quark mass. A much better step toward fixing the parameters of the standard model would be to measure the $B_s \bar{B}_s$ mixing. The ratio of $B_s$ to $B^0$ mixing provides constraint on the KMC matrix elements. In particular, the $\Delta M / \Gamma$ ratio is given by

$$(\Delta M / \Gamma)_s / ((\Delta M / \Gamma)_d = |V_{ts} / V_{td}|^2 (B_{B^+B^0})_s / (B_{B^+B^0})_d.)$$

Currently there are no known plans to measure $B_s$ mixing. Since the mixing parameter, $r_s$, is expected to be close to unity, it must be measured accurately to extract $(\Delta M / \Gamma)_s$.

J. Exclusive Hadronic B Decays

In spite of the large data samples (Argus has approximately 172 pb$^{-1}$ and CLEO has 212 pb$^{-1}$ on the $T(4S)$), only a small fraction of the final states have been reconstructed. The measured $B^+$ and $B^0$ hadronic branching fractions are listed in Tables VIII and IX. These are mostly low multiplicity final states with at most one $\pi^0$, which are the

<table>
<thead>
<tr>
<th>DECAY MODE</th>
<th>ARGUS</th>
<th>CLEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \pi^-$</td>
<td>0.20 ± 0.08 ± 0.06</td>
<td>0.44 ± 0.07 ± 0.07</td>
</tr>
<tr>
<td>$B^0 \rho^-$</td>
<td>1.3 ± 0.4 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>$B^0 \pi^- \pi^+$</td>
<td>0.39 ± 0.09 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>$B^0 \pi^- \pi^+$</td>
<td>2.0 ± 0.9</td>
<td></td>
</tr>
<tr>
<td>$B^+ \pi^-$</td>
<td>0.40 ± 0.14 ± 0.12</td>
<td></td>
</tr>
<tr>
<td>$B^+ \rho^-$</td>
<td>1.0 ± 0.6 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>$B^{*+} \pi^- \pi^+$</td>
<td>0.26 ± 0.14 ± 0.07</td>
<td>0.14 ± 0.08 ± 0.03</td>
</tr>
<tr>
<td>$B^{*0} \pi^- \pi^+$</td>
<td>1.8 ± 0.7 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>$B^{*+} \pi^- \pi^- \pi^+$</td>
<td>0.28 ± 0.14 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>$J/\psi K^-$</td>
<td>0.07 ± 0.03 ± 0.01</td>
<td>0.08 ± 0.02 ± 0.02</td>
</tr>
<tr>
<td>$\psi' K^-$</td>
<td>0.18 ± 0.08 ± 0.04</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>$J/\psi K^{*-}$</td>
<td>0.16 ± 0.11 ± 0.03</td>
<td>0.13 ± 0.09 ± 0.03</td>
</tr>
<tr>
<td>$\psi' K^{*-}$</td>
<td>&lt; 0.5</td>
<td>&lt; 0.35</td>
</tr>
<tr>
<td>$J/\psi K^{*-} \pi^-$</td>
<td>&lt; 0.16</td>
<td>0.12 ± 0.06 ± 0.03</td>
</tr>
<tr>
<td>$\psi' K^{*-} \pi^-$</td>
<td>0.19 ± 0.11 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5.82 ± 1.05 ± 0.78</td>
<td>3.30 ± 0.92 ± 0.13</td>
</tr>
</tbody>
</table>
easiest to reconstruct. They all contain either a D, D_s, or a ψ meson. On average there are approximately 10 charged particles and 10 photons in a BB final state[42]. Hence, to tabulate B meson decays we have to upgrade reconstruction of the high multiplicity final states, including those with two or three s's. CLEO has a new electromagnetic calorimeter which will allow efficient s reconstruction thereby improving event reconstruction efficiency. However, the combinatorics of reconstructing high multiplicity final states makes it very difficult. The number of combinations could be drastically reduced, if one were able to separate the main BB vertex from the D meson decay vertex. This idea motivated ARGUS to install a new vertex detector with capability of 3 dimensional high precision track reconstruction. With these detector upgrades both experiments should be able to extend their tabulation of exclusive branching fractions.

K. Rare Decays of B Mesons

Searches have been made for a large number of rare decay modes. These include non-charm hadronic and semileptonic final states[43], b+s transitions via Penguin Diagrams[44], semileptonic decay to baryons[45], and flavor changing neutral current leptonic final states[46]. Nothing has been seen. Aside from the last category which is beyond current considerations, it is important to measure a substantial number of these final states to better define the parameters of the standard model and improve

Table IX Exclusive Hadronic Branching Ratios of B° Mesons

The B° Branching Ratios are given in %, assuming f_{oo} = f_{+-} = 0.5.

<table>
<thead>
<tr>
<th>DECAY MODE</th>
<th>ARGUS</th>
<th>CLEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>D^+π^-</td>
<td>0.48 ± 0.11*0.11</td>
<td>0.25 ± 0.06*0.04</td>
</tr>
<tr>
<td>D^+ρ^-</td>
<td>0.9 ± 0.5 ±0.3</td>
<td></td>
</tr>
<tr>
<td>D^+π^-π^+π^-</td>
<td>0.60 ± 0.16 ±0.10</td>
<td></td>
</tr>
<tr>
<td>D^0D^-</td>
<td>1.2 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>D^0π^-π^+</td>
<td>&lt; 0.04</td>
<td></td>
</tr>
<tr>
<td>D^0π^-π^0</td>
<td>0.28 ± 0.09 ±0.06</td>
<td></td>
</tr>
<tr>
<td>D^0ρ^-</td>
<td>1.8 ± 0.4 ±0.5</td>
<td></td>
</tr>
<tr>
<td>D^0π^-π^-π^-</td>
<td>0.7 ± 0.3 ±0.3</td>
<td></td>
</tr>
<tr>
<td>D^0π^-π^-π^-</td>
<td>1.2 ± 0.3 ±0.4</td>
<td></td>
</tr>
<tr>
<td>D^0π^-π^-π^-</td>
<td>4.1 ± 1.5 ±1.6</td>
<td></td>
</tr>
<tr>
<td>J/ψK^0</td>
<td>0.04 ± 0.03*0.01</td>
<td>0.03 ± 0.15*0.01</td>
</tr>
<tr>
<td>ψK^0</td>
<td>&lt; 2.3</td>
<td>&lt; 0.08</td>
</tr>
<tr>
<td>J/ψK^0</td>
<td>0.11 ± 0.05 ±0.02</td>
<td>0.11 ± 0.05 ±0.03</td>
</tr>
<tr>
<td>ψK^0</td>
<td>&lt; 0.23</td>
<td>0.13 ± 0.09 ±0.03</td>
</tr>
<tr>
<td>J/ψK^*π^-</td>
<td>0.10 ± 0.04 ±0.03</td>
<td></td>
</tr>
<tr>
<td>ψK^-π^-</td>
<td>&lt; 0.1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9.61 ± 1.69 ±1.78</td>
<td>6.15 ± 1.22 ±1.36</td>
</tr>
</tbody>
</table>
our ability to calculate the branching ratios.

L. Status of Measured B Meson Decays

A summary of what branching fractions have been measured is shown in Table X. One notes that all of the listed final states have a CHARM quark. The inclusive branching fractions sum to 0.94. However, since there are c quarks from the W boson in addition to the b decay vertex, there are B meson decays to D and D̄ mesons (or D̄ and D̄̄ mesons). The W boson transforms to cs approximately 15% of the time, and therefore, if the b quark always transforms to cW, one expects the inclusive to sum to 1.15. In other words, 80% of the inclusive decays have been tabulated. The measured exclusive branching fractions account for only 22% of the final states. Approximately 67% of the semileptonic decays are D̄eν or D̄eν, only 8% of the hadronic decays have been reconstructed.

Table X, Measured BRANCHING Fractions

Averaged over B̄ and B−

The inclusive semileptonic branching ratio is the sum of the electron, muon, and tau final states, even though the decay B+Xν has not been observed.

<table>
<thead>
<tr>
<th>MODE</th>
<th>INCLUSIVE</th>
<th>EXCLUSIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semileptonic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D̄,D+</td>
<td>0.24</td>
<td>0.14</td>
</tr>
<tr>
<td>Hadronic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D̄,D+</td>
<td>0.51</td>
<td>0.052</td>
</tr>
<tr>
<td>D</td>
<td>0.10</td>
<td>0.016</td>
</tr>
<tr>
<td>D̄</td>
<td>0.01</td>
<td>0.005</td>
</tr>
<tr>
<td>A</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.94</td>
<td>0.22</td>
</tr>
</tbody>
</table>

FUTURE EXPECTATIONS

It is clear we have much work before being able to claim the decay of CHARM and BOTTOM are understood. Tabulating the exclusive branching ratios such that they sum to over 90% is important and not easy. As mentioned earlier, the measurement of some rare decay modes is useful for extracting certain parameters in the Standard Model, and checking out our ability to calculate various decay processes.

BEP C has begun operating. If they attain higher luminosity than SPEAR, and have a better detector, they could provide more accurate absolute branching ratios for the major CHARM decay modes. There are a large number of new fixed target experiments starting up. They will supply the relative CHARM branching ratios for the higher multiplicity final states. They will also provide improvement and/or confirmation of the CHARM lifetimes. The real uncertainty is whether fixed target experiments will be able to expand their programs to reconstructing BOTTOM decay. The Hadron Colliders and LEP experiments are beginning to reconstruct B mesons decaying to J/ψK and J/ψK. It will be interesting to see whether they will be able to use these events. The real challenge for them is to measure B̄ and B′ lifetimes.

ARGUS has installed a new vertex chamber in their detector, and CLEO has built a new detector which contains an electromagnetic calorimeter of resolution comparable to the Crystal Ball. However, for all of the experiments, it will require several years to accumulate sufficient data and then quite a while after that to produce significant improvement in our knowledge of CHARM and BOTTOM decay. I hope it happens before I retire.
ACKNOWLEDGEMENTS

It is a pleasure to acknowledge useful discussions I had with H. Schroder and D. MacFarlane prior to the conference regarding the ARGUS submissions and other subjects related to heavy quark physics. I also wish to thank the conference committee for the invitation to give this summary talk. It helped update me on what has been happening.

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7. "Measurement of the Form Factors in the Decay D<sup>0</sup><sup>→</sup> K<sup>±</sup>π<sup>0</sup>ν<sub>µ</sub>ν<sub>ν</sub> J.C. Anjos et al, UCSB-HEP-90-11, June 1990. (Submitted to PRL in briefer form)
9. Presentation by N. W. Reay (Ohio State University) at the Heavy Quark Parallel Session
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25. Presentation by H. Schroder (ARGUS) at the Heavy Quark Parallel Session.
26. There have been several papers attempting to explain the τ(4S) direct decay to ϒ.
27. "A Possible Mechanism for NON BB Decays of the τ(4S)!
28. "Remarks on NON BB Decay of τ(4S)!
27. After averaging over models, the ARGUS semileptonic branching fraction is 
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"Search for Rare Semileptonic B-Meson Decays" DESY 89-163 (Dec. 1989)
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