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Michael V. Danilov

HEAVY FLAVOUR PHYSICS

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HEAVY FLAVOUR PHYSICS

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ABSTRACT

Recent results on heavy flavours from non-LEP experiments are reviewed. In the beauty sector emphasis is made on decays useful for CP violation studies and on processes relevant to the determination of the CKM matrix: semileptonic decays, $B\overline{B}$ mixing, and searches for $b \to s\gamma$ transitions. The discussion on charm is limited mainly to Cabibbo-suppressed and semileptonic decays and new measurements of D^* and D_s decays. Finally, new precise measurements of τ lepton decays (including LEP results) are presented.

INTRODUCTION

The physics of heavy flavours is a very rich field. It comprises searches for new phenomena, determination of the fundamental parameters of the electroweak theory, quantitative tests of Quantum Chromodynamics (QCD), and studies of non-perturbative processes in strong interactions for which a model independent theoretical approach has yet to be developed.

The search for new effects beyond the present theory is the main motivation behind studies of heavy flavours. One should keep in mind how drastically our understanding of nature was changed by studies of the semiheavy strange quark, recalling that, at the time of the discovery of particle-antiparticle oscillations, P and CP violation, the strange quark was the heaviest known flavour.

There is a hope that investigation of charm and especially beauty will bring equally important surprises. The reason behind this expectation is the large mass and long lifetime of c and b quarks. In particular further studies of the beauty quark are expected to play a crucial role in solving the puzzle of CP violation. Beauty and charmed particle decays can be sensitive to phenomena at a larger mass scale than presently available at accelerators, for instance to charged Higgs bosons or supersymmetric particles.

The tau lepton is thought to be the sequential lepton of the third generation. However, this assumption is not well tested and further studies could bring surprises. Moreover, there are some indications of discrepancy between theoretical expectations and experimental data which question even $e - \mu - \tau$ universality.

From the LEP studies we know that there are only 3 light neutrino species and therefore most probably only 3 families of quarks and leptons. This limited number of quark and lepton families should reflect some fundamental feature of nature which is yet to be discovered. At present the quark and lepton sectors of the Standard Model (SM) contain the largest number of free parameters which are not predicted by theory. There are 6 quark and 3 lepton masses (assuming neutrinos are massless), and 4 independent parameters of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, V, which rotates the quark mass eigenstates (d, s, b) into the weak eigenstates (d', s', b'):

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

It is possible that a more fundamental theory will eventually specify these parameters. Meanwhile experimental measurements are extremely important in giving some indication about what a more complete theory should look like. Eight out of the 13 parameters mentioned above can be determined from studies of heavy flavours.

Finally, heavy quarks and leptons provide unique possibilities for studying strong interactions. The large masses of the b and c quarks considerably simplify theoretical calculations and allow, in many cases, quantitative tests of QCD. Tau lepton decays offer very clean initial conditions for a study of low mass resonances.

The top quark has not yet been found [1].

Therefore, this talk is devoted to beauty and charm particles and to the τ lepton. Due to space limitations only recent results are mainly discussed, with apologies for unavoidable personal bias in the selection of topics. There are many excellent comprehensive reviews on these subjects [2] where more details can be found. LEP results on heavy flavours are discussed in a separate talk by Roudeau [3].

The first part of the paper is devoted to B mesons. The topics include nonleptonic and semileptonic decays, updates on $B\overline{B}$ mixing and searches for $b \to s\gamma$ transitions. The available information on the CKM matrix elements is then summarized in terms of the unitarity triangle. Charmed particles are discussed in the second part with the main emphasis on Cabibbo-suppressed and semileptonic decays. The third part is devoted to decays of τ lepton including the LEP results.

BEAUTY

Before LEP, information about b quarks came mainly from the e^+e^- storage rings DORIS II and CESR, working just above the threshold for $e^+e^- \to B\overline{B}$. The reason for this is the existence of the $\Upsilon(4S)$ resonance which decays into $B^0\overline{B^0}$ and B^+B^- final states with $J^P = 1^-$. The $\Upsilon(4S)$ resonance has a relatively large peak cross section of about $1nb$ and provides very clean conditions with accurately known (within a few MeV) B meson energy. Tagging one B meson uniquely identifies the other produced along with it. The ARGUS and CLEO 1.5 experiments have collected 209×10^3 and 244×10^3 $\Upsilon(4S)$ decays, respectively. In 1989 the CLEO II detector, with an excellent CsI electromagnetic calorimeter, was brought into operation. More than a million of B decays have been collected with this detector. The first results from this sample are now starting to appear.

The total width of $\Upsilon(4S)$ is 3 orders of magnitude larger than the widths of Υ resonances which lie below the $B\overline{B}$ threshold. Therefore it is assumed in this talk that the $\Upsilon(4S)$ decays only into $B\overline{B}$ pairs and that non-$B\overline{B}$ decays of the $\Upsilon(4S)$ can be neglected. However, searches for non-$B\overline{B}$ decays are discussed in the next section.

1. Search for non-$B\overline{B}$ Decays of $\Upsilon(4S)$

More than a year ago CLEO [4] and ARGUS [5] observed fast J/ψ mesons at the $\Upsilon(4S)$ energy with momenta above the kinematic limit for production in B decays (see Fig.1). No signal was seen in the continuum by either experiment, indicating that the J/ψ were produced directly in $\Upsilon(4S)$ decays. However, the probability that the signal observed at the $\Upsilon(4S)$ was due to J/ψ production in the continuum was a non-negligible, being about 1% in both experiments. Nevertheless, CLEO interpreted the signal as the observation of non-$B\bar{B}$ decays of $\Upsilon(4S)$ into J/ψ [4]. ARGUS did not publish their result because they believed the signal could be a statistical fluctuation in J/ψ production from the continuum.

Indication of direct $\Upsilon(4S)$ decays into $J/\psi X$ created a lot of excitement because the decay width for $\Upsilon(1S) \to J/\psi X$ was 3 orders of magnitude smaller [6], so that these unusual $\Upsilon(4S)$ decays could indicate new physics. Several authors discussed a possibility that $\Upsilon(4S)$ was not a pure $b\bar{b}$ state, but had some gluon or light quark admixture [7,8,9,10]. On the experimental side there is no evidence for any other non-$B\bar{B}$ final states in $\Upsilon(4S)$ decays. The CUSB search [11] for direct photon production predicted in some models [8,7] has led to 90% confidence level upper limits $BR(\Upsilon(4S) \to \gamma X) < 0.65\%$ for $E_\gamma \sim 500\ MeV$ and $BR(\Upsilon(4S) \to \gamma X) < 0.08\%$ for $E_\gamma \sim 4-5\ GeV$. The first limit is already in contradiction with one of the theoretical predictions [8], while the second is only marginally consistent with another explanation [7]. By comparing lepton and dilepton rates at the $\Upsilon(4S)$, CLEO [12] has set an upper limit on the fraction of non-$B\bar{B}$ decays $f_{non-B\bar{B}} = 1 - f_+ - f_0 < 14\%$ at 95% CL.

At this conference CLEO [13] has presented a preliminary study of high momentum J/ψ's in the new data sample collected with CLEO II detector. In contrast with their previous study, CLEO now observes continuum production of J/ψ mesons with momenta above 2 GeV/c (See Fig.1d). In the combined new and old continuum data sample there are 12 events in J/ψ region with an estimated background of 3.6 ± 0.6 events. The probability that a Poisson distribution with a mean of 3.6 will give rise to an upward fluctuation of 12 or more events is 3.7×10^{-4}. At

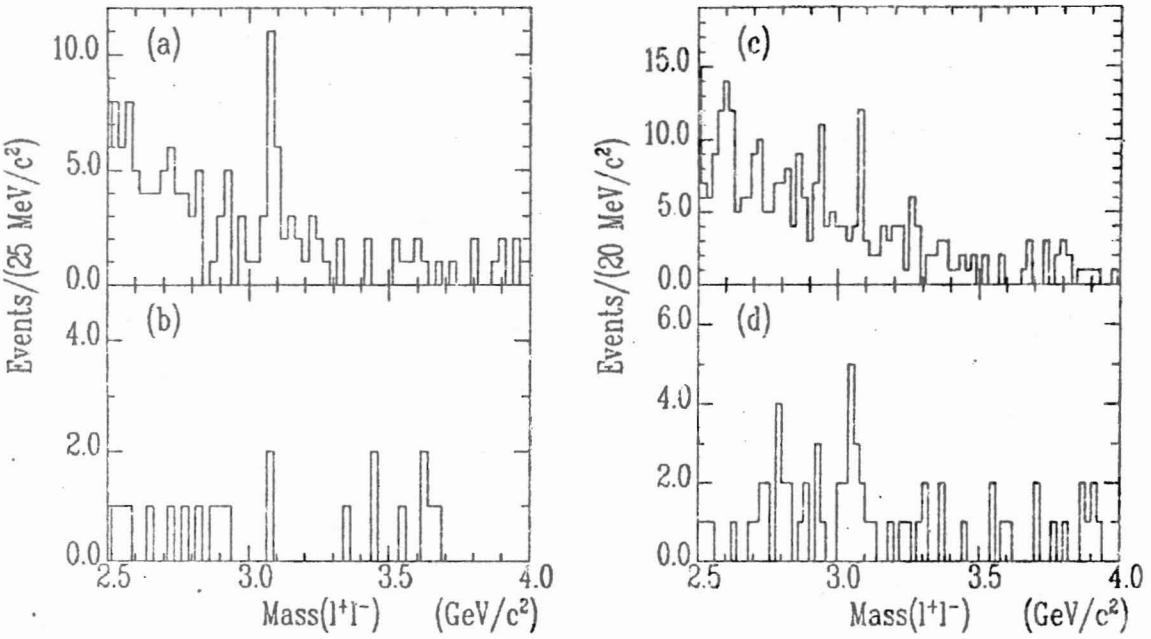

Figure 1: Dilepton invariant mass distributions (for $x > 0.38$) for CLEO 90 (left) and CLEO 91 (right) data. (a) and (c) on $\Upsilon(4S)$, (b) and (d) off $\Upsilon(4S)$.

the $\Upsilon(4S)$ energy the rate of fast J/ψ mesons is 3 times smaller in the new data than in the old (see Fig. 1c). Consequently in the combined data sample the excess of J/ψ production at the $\Upsilon(4S)$ beyond the continuum component is only 0.5 ± 9.6 events, an average which is marginally consistent with the CLEO 90 result. At the moment CLEO has no explanation, other than a statistical fluctuation, for this development.

In order to determine

$$R_{J/\psi} = \sigma(e^+e^- \to J/\psi X)/\sigma(e^+e^- \to \mu^+\mu^-)$$

CLEO combines continuum and $\Upsilon(4S)$ data, assuming that all fast J/ψ ($x = p_{J/\psi}/p_{beam} > 0.38$) are produced in continuum. This leads to

$$R_{J/\psi}(x > 0.38) = (1.0 \pm 0.3 \pm 0.3) \times 10^{-3},$$

a value in reasonably good agreement with theoretical predictions for J/ψ production in the continuum near 10 GeV, which range from $R_{J/\psi} = 3 \times 10^{-4}$ to $R_{J/\psi} = 2 \times 10^{-3}$ [14].

2. Nonleptonic Decays of B mesons

The masses of B mesons have been measured using reconstructed hadronic B decays. The results from the fits to the ARGUS [15,16] and CLEO [12,17] data are given in table 1. The difference between the $\overline{B}^0$ and B^- masses is consistent with zero. The mass splitting has important implications for theoretical estimates of the ratio, f_+/f_0, where f_0 and f_+ are the branching ratios for $\Upsilon(4S) \to B^0\overline{B^0}$ and $\Upsilon(4S) \to B^+B^-$ respectively. A knowledge of f_+ and f_0 is important for the determination of B meson branching ratios and hence for the extraction of the fundamental parameters of SM. Recent theoretical estimates [18,19,20], which include the momentum dependence of the $\Upsilon(4S) \to B\bar{B}$ vertex function and the effects of the B^- and B^0 form factors, indicate that $f_+/f_0 = 1.00 \pm 0.05$, where the error reflects the theoretical uncertainty in the momentum dependence of the vertex function. Throughout this paper the ratio f_+/f_0 is fixed to one and the systematic error is not included in branching ratios of B mesons.

Tables 2 and 3 list B^0 and B^- hadronic branching ratios measured by ARGUS [15,16] and CLEO [12,17]. At present about 15% of hadronic B^- decays and about 20% of hadronic $\overline{B^0}$ decays have been observed. All branching ratios are calculated using MARK III measurements

Table 1: ARGUS and CLEO results for B meson masses.

	M_{B^0}	M_{B^-}	$M_{B^0} - M_{B^-}$
ARGUS	$5279.4 \pm 0.6 \pm 2.0$	$5280.6 \pm 0.8 \pm 2.0$	$-1.2 \pm 1.0 \pm 0.5$
CLEO	$5278.5 \pm 0.4 \pm 2.0$	$5278.4 \pm 0.4 \pm 2.0$	$+0.1 \pm 0.6 \pm 0.5$
Average	$5278.8 \pm 0.3 \pm 2.0$	$5278.8 \pm 0.4 \pm 2.0$	$-0.2 \pm 0.5 \pm 0.5$

Table 2: Branching ratios for nonleptonic $\overline{B^0}$ decays in % .

Mode	ARGUS	CLEO	average	BSW model
$\bar{B}^0 \to D^+\pi^-$	0.48 ± 0.16	0.28 ± 0.08	0.32 ± 0.07	0.39
$\bar{B}^0 \to D^+\rho^-$	0.9 ± 0.6	—	0.9 ± 0.6	1.03
$\bar{B}^0 \to D^0\rho^0$	< 0.3	< 0.06	< 0.06	0.00
$\bar{B}^0 \to D^+\pi^-\pi^-\pi^+$	—	0.8 ± 0.3	0.8 ± 0.3	
$\bar{B}^0 \to D^+D_s^-$	1.4 ± 1.2	0.9 ± 0.5	1.0 ± 0.5	1.56
$\bar{B}^0 \to D^+D_s^{*-}$	2.3 ± 1.9	—	2.3 ± 1.9	0.92
$\bar{B}^0 \to D^{*+}\pi^-$	0.28 ± 0.11	0.36 ± 0.10	0.32 ± 0.09	0.31
$\bar{B}^0 \to D^{*+}\pi^-\pi^0$	1.8 ± 0.6	—	1.8 ± 0.6	
$\bar{B}^0 \to D^{*+}\rho^-$	0.7 ± 0.4	1.9 ± 1.4	0.8 ± 0.4	0.97
$\bar{B}^0 \to D^{*+}\pi^-\pi^-\pi^+$	1.2 ± 0.6	1.6 ± 0.5	1.4 ± 0.4	
$\bar{B}^0 \to D^{*+}a_1^-$	—	1.8 ± 0.8	1.8 ± 0.8	1.34
$\bar{B}^0 \to D^{*+}\pi^-\pi^-\pi^+\pi^0$	4.1 ± 2.2	—	4.1 ± 2.2	
$\bar{B}^0 \to D^{*+}D_s^-$	1.2 ± 0.9	1.8 ± 1.0	1.5 ± 0.7	0.7
$\bar{B}^0 \to D^{*+}D_s^{*-}$	2.3 ± 1.3	—	2.3 ± 1.3	2.54
$\bar{B}^0 \to J/\psi\bar{K}^0$	0.08 ± 0.06	0.06 ± 0.04	0.06 ± 0.03	0.03
$\bar{B}^0 \to J/\psi\bar{K}^{*0}$	0.11 ± 0.05	0.14 ± 0.06	0.12 ± 0.05	0.12
$\bar{B}^0 \to J/\psi K^-\pi^+$	—	0.10 ± 0.05	0.10 ± 0.05	
$\bar{B}^0 \to \psi'\bar{K}^0$	< 0.28	< 0.15	< 0.15	
$\bar{B}^0 \to \psi'\bar{K}^{*0}$	< 0.23	0.14 ± 0.09	0.14 ± 0.09	
$\bar{B}^0 \to \psi'K^-\pi^+$	< 0.10	—	< 0.10	

for the decays of D and D^* mesons [21]. D_s^+ branching ratios are reliably known only relative to BR($D_s^+ \to \phi\pi^+$) *. The latter has been measured using indirect methods and it is hard to estimate the relevant systematic errors. Therefore a fixed value of 2.7% is assumed throughout this paper for BR($D_s^+ \to \phi\pi^+$) [22]. In order to compare different experiments, results have been rescaled where necessary to these common values for charm branching ratios.

The last column of tables 2 and 3 shows the predictions of the BSW model [23] with the two free parameters of the model fixed by a fit to the measured branching ratios [12].

*References in this paper to a specific charged state also imply the charge conjugate state.

2.1 Decays $B \to D_s^{(*)}D^{(*)}$

Decays into channels with a D_s or D_s^* meson account for about one third of known hadronic B meson branching ratios. Three decay channels with a $D_s^{(*)}$ have been first observed by CLEO [24]. Recently ARGUS [16] obtained evidence for all eight possible decay modes $D_s^{(*)}D^{(*)}$ (see Fig.2 and tables 2, 3). The rates for the modes involving a D_s meson depend on the annihilation constant f_{D_s} (see Fig. 3), which reflects basic dynamical properties of a bound $q\bar{q}$ system related to its size. Knowledge of meson decay constants is essential for the extraction of fundamental CKM parameters from many weak processes, including $B^0\overline{B^0}$ mixing. Very little is known experimentally about the decay constants

Table 3: Branching ratios for nonleptonic B^- decays in % .

Mode	ARGUS	CLEO	average	BSW model
$B^- \to D^0\pi^-$	0.20 ± 0.10	0.51 ± 0.09	0.40 ± 0.07	0.29
$B^- \to D^0\rho^-$	1.3 ± 0.6	—	1.3 ± 0.6	0.91
$B^- \to D^0\pi^-\pi^-\pi^+$	—	1.2 ± 0.4	1.2 ± 0.4	
$B^- \to D^0 D_s^-$	2.1 ± 1.1	2.2 ± 0.9	2.2 ± 0.7	1.56
$B^- \to D^0 D_s^{*-}$	1.4 ± 1.0	-	1.4 ± 1.0	0.92
$B^- \to D^{*0}\pi^-$	0.40 ± 0.18	0.7 ± 0.2	0.52 ± 0.15	0.20
$B^- \to D^{*0}\rho^-$	1.0 ± 0.7	—	1.0 ± 0.7	0.71
$B^- \to D^{*0} D_s^-$	1.1 ± 0.8	—	1.1 ± 0.8	0.70
$B^- \to D^{*0} D_s^{*-}$	2.7 ± 1.5	—	2.7 ± 1.5	2.52
$B^- \to D^{*+}\pi^-\pi^-$	0.26 ± 0.16	< 0.4	0.26 ± 0.16	
$B^- \to D^{*+}\pi^-\pi^-\pi^0$	1.8 ± 0.9	—	1.8 ± 0.9	
$B^- \to D^{*+}\pi^-\pi^-\pi^-\pi^+$	< 1.0	—	< 1.0	
$B^- \to J/\psi K^-$	0.07 ± 0.03	0.08 ± 0.03	0.08 ± 0.02	0.03
$B^- \to J/\psi K^{*-}$	0.16 ± 0.11	0.13 ± 0.09	0.14 ± 0.07	0.12
$B^- \to J/\psi K^-\pi^-\pi^+$	< 0.16	0.12 ± 0.07	0.12 ± 0.07	
$B^- \to \psi' K^-$	0.18 ± 0.09	< 0.05	0.18 ± 0.09	
$B^- \to \psi' K^{*-}$	< 0.49	< 0.35	< 0.35	
$B^- \to \psi' K^-\pi^-\pi^+$	0.19 ± 0.12	—	0.19 ± 0.12	
$B^- \to \chi_{c1} K^-$	0.19 ± 0.14	—	0.19 ± 0.14	

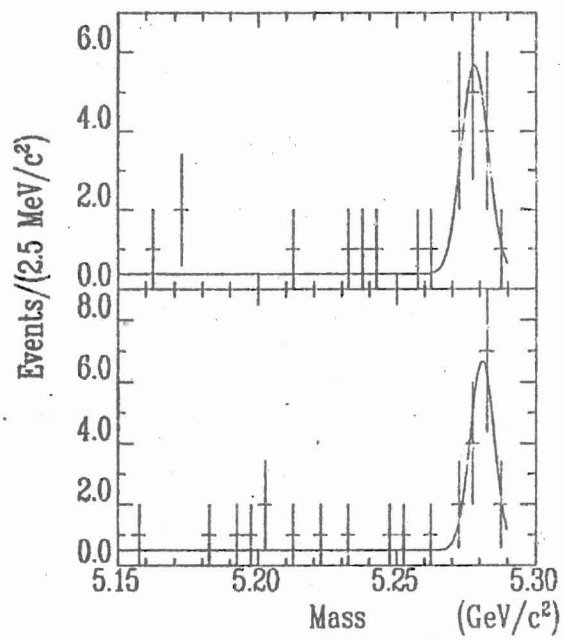

Figure 2: Mass distributions of a) $B^0 \to D_s^{(*)+}D^{(*)-}$ and b) $B^+ \to D_s^{(*)+}\overline{D}^{(*)0}$.

of D and B mesons. Only MARK III has established an upper limit on $f_D < 290 MeV$ [25].

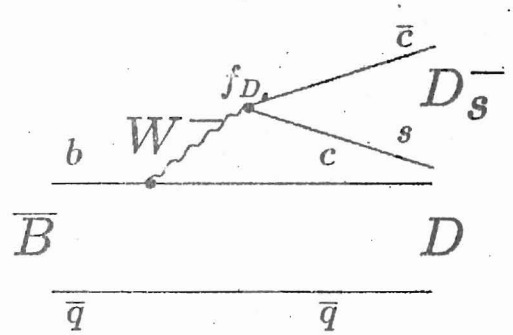

Figure 3: Diagram for $B \to D_s^{(*+)}\overline{D^{(*)}}$ decays.

Assuming factorization one can estimate f_{D_s} from the measurements of $B \to D_s^{(*)}\overline{D}^{(*)}$. Using predictions of so called Heavy Quark Effective Theory (HQET) [26,27] one finds $f_{D_s^{(*)}} = (296 \pm 48) MeV$ (CLEO [28,27]) and $f_{D_s^{(*)}} = (267 \pm 28) MeV$ (ARGUS [16]). In HQET values of f_{D_s} and $f_{D_s^*}$ are equal and therefore have been averaged. For different values of $BR(D_s^+ \to$

$\phi\pi^+$) the decay constant f_{D_s} scales as $(2.7\%/BR(D_s^+ \to \phi\pi^+))^{1/2}$. The experimental error on f_{D_s} is quite small. However, one should not forget the important assumption of factorization which is used in this method. The estimates for f_{D_s} obtained by ARGUS and CLEO are closer to the upper end of the theoretical predictions, which range from 91 to 590 MeV, but are mainly concentrated between 200 and $300 MeV$ (for a compilation see, e.g.,[16]). A large value of f_{D_s} implies a large

$$BR(D_S^+ \to \tau^+\nu_\tau) = 2.74\%(f_{D_S}/200MeV)^2$$

[27] and therefore improves prospects of ν_τ detection.

2.2 Evidence for χ_{c1} Production in B Decays

Production of $c\bar{c}$-states in B meson decays offers a unique opportunity for study of the interplay between the weak and strong interactions. These processes are expected to proceed through diagrams shown in Fig. 4. According to theoretical models, J/ψ and ψ' mesons are produced by the vector current, while the axial vector current is responsible for transitions to η_c and χ_{c1} mesons [29]. An experimental study of the latter is an important complement to previous results on the J/ψ and ψ' channels, testing the various theoretical approaches. Production of the other charmonium states, χ_{c0} and χ_{c2}, in B meson decays is forbidden, if the effect of soft-gluon exchange is ignored [29]. One should also mention that B meson decays to charmonium states like $B^0 \to J/\psi K_s^0$ or $B^0 \to J/\psi K^{0*}$ are considered to be among the best candidates for future studies of CP violation. Decays to χ_{c1} and η_c mesons could also be useful, provided the corresponding branching ratios are large enough.

Recently ARGUS obtained the first evidence for inclusive and exclusive B decays into χ_{c1} mesons. The search for χ_c mesons is made in the decay mode $\chi_c \to J/\psi\gamma$, where the J/ψ is reconstructed in the leptonic mode $J/\psi \to e^+e^-(\mu^+\mu^-)$. Photons which can be combined with another photon to form a pair within ± 70 MeV/c^2 (about $\pm 3\sigma$) of the nominal π^0 meson mass are rejected in order to suppress background from π^0 meson decays. Finally, the $J/\psi\gamma$ combinations are required to have momenta less

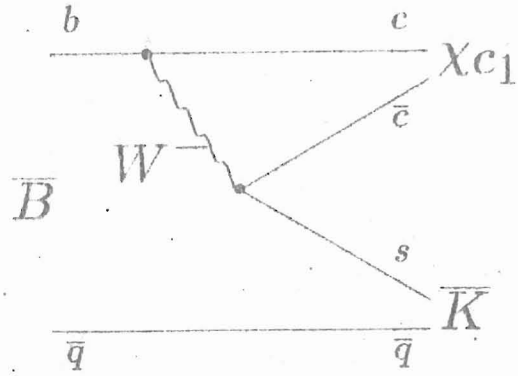

Figure 4: Diagram for $B \to \chi_{c1}K$ decay.

than 1.7 GeV/c, which is the kinematic limit for χ_c production in B meson decays.

The mass spectrum for all accepted $J/\psi\gamma$ combinations is shown in Fig.5 after continuum subtraction. An enhancement in the χ_c mass region is seen in this plot, while the continuum contribution is small and exhibits no enhancement in the signal region. The solid line in Fig.5 represents a Monte Carlo estimate of the background normalized to the number of lepton pairs in the J/ψ mass region.

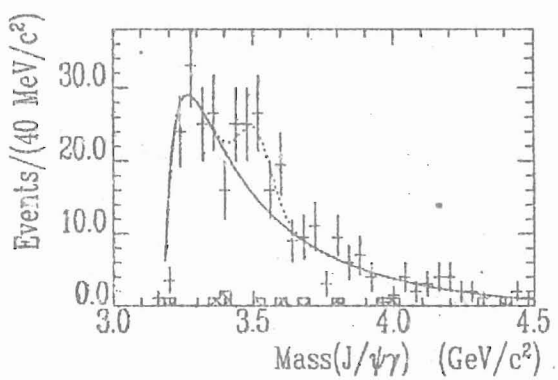

Figure 5: Invariant mass distributions of $J/\psi\ \gamma$ combinations for direct $\Upsilon(4S)$ decays (points) and nearby continuum (histogram). The solid line shows the expected background.

Fitting the signal with a single Gaussian describing χ_{c1} contribution ARGUS obtains 33 ± 11 events. Under the assumption of no χ_{c2} produc-

tion, this corresponds to

$$\mathrm{Br}(B \to \chi_{c1} X) = (1.05 \pm 0.35 \pm 0.25)\%.$$

ARGUS also observes four candidates for $B^{\pm}$ decays into $\chi_{c1} K^{\pm}$ (see Fig.6) which leads to

$$BR(B^{\pm} \to \chi_{c1} K^{\pm}) = (0.19 \pm 0.13 \pm 0.06)\%.$$

Such a large branching ratio implies that the analogous decay $B^0 \to \chi_{c1} K_s^0$ will be useful in future searches for CP violation in B decays, particularly if background allows the use of direct χ_{c1} decays into $3(\pi^+\pi^-)$, $2(\pi^+\pi^-)$, $K^+K^-\pi^+\pi^-$ or other final states.

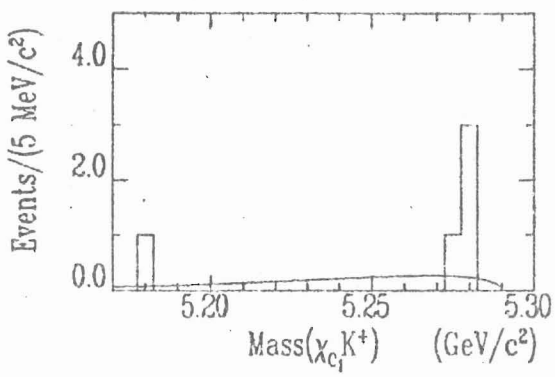

Figure 6: $\chi_{c1} K^+$ mass (ARGUS)

At this conference, CLEO confirmed the ARGUS observation of χ_{c1} production in B decays. After a similar analysis they observed $24.4 \pm 6.5 \pm 4.4$ events at the χ_{c1} mass (see Fig. 7) which corresponds to

$$\mathrm{Br}(B \to \chi_{c1} X) = (0.54 \pm 0.15 \pm 0.14)\%.$$

CLEO has a χ_{c1} mass resolution which is 4.5 times better than that of ARGUS. Therefore they are able to show that the signal is indeed due to χ_{c1} production and that there is no indication of the χ_{c2} meson, in agreement with the theoretical expectations [29]. CLEO also observes four candidates for $B^{\pm}$ decays into $\chi_{c1} K^{\pm}$ which leads to

$$BR(B^{\pm} \to \chi_{c1} K^{\pm}) = (0.10 \pm 0.06)\%.$$

Averaging ARGUS and CLEO results one obtains

$$\mathrm{Br}(B \to \chi_{c1} X) = (0.64 \pm 0.19)\%,$$
$$\mathrm{Br}(B^{\pm} \to \chi_{c1} K^{\pm}) = (0.11 \pm 0.055)\%.$$

The inclusive branching ratio is twice as large as the theoretical predictions [29]. After subtracting cascade contributions, one concludes that direct yields of J/ψ, ψ' and χ_{c1} are comparable, being approximately 0.70%, 0.46%, and 0.60%, respectively. This again does not agree well with the theoretical predictions [29], although errors are still large.

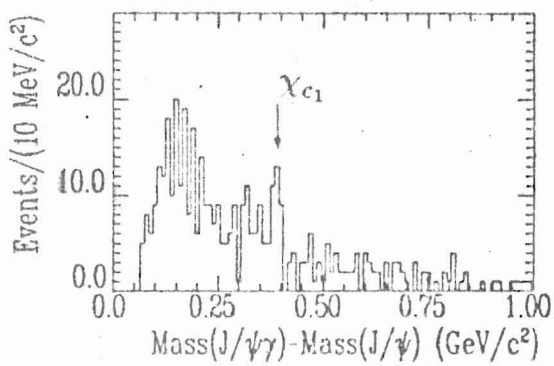

Figure 7: $M(J/\psi\gamma)$ $M(J/\psi)$ mass difference.

2.3 Measurement of J/ψ Polarization in B Decays

B decays into $J/\psi K^{*0}$ with $K^{*0} \to K_s^0 \pi^0$ can also be useful for CP violation studies [30], depending on the relative helicity population of the K^{*0}. In particular, the (0,0) final state in this decay is a pure CP eigenstate. The relative fraction of the (0,0) state can be determined by measuring J/ψ or K^{0*} polarization.

The first evidence for J/ψ polarization has been obtained by ARGUS [31] from an analysis of the decay angle Θ of the lepton from the J/ψ decay in the cm-system of the J/ψ meson with respect to the direction of the J/ψ in the B meson cm-system. For fast J/ψ mesons with momenta above 1.4 GeV/c the angular distribution exhibits a $\sin^2\Theta$ distribution (see Fig.8a) as expected for a (0,0) state (in contrast to the $1+\cos^2\Theta$ distribution for $(\pm1,\pm1)$ states). A fit to the measured angular distribution of the form

$$\frac{d\sigma}{d\Omega} \propto 1 + \alpha \times cos^2\Theta$$

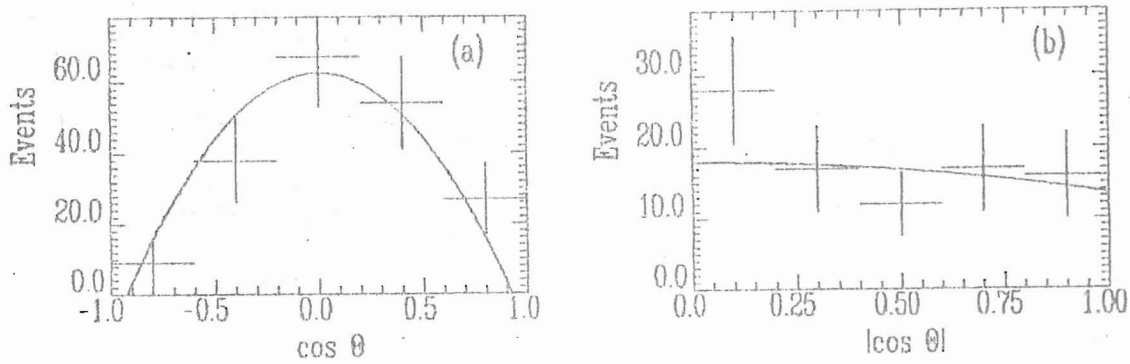

Figure 8: ARGUS(a) and CLEO(b) decay angular distributions of leptons from J/ψ mesons produced in $\Upsilon(4S)$ decays with $p(J/\psi) > 1.4GeV/c$.

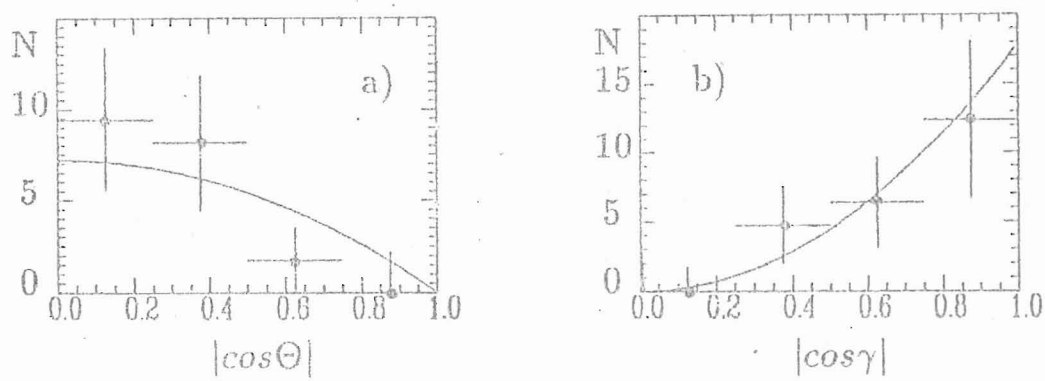

Figure 9: Acceptance corrected distributions of the helicity angles for decays of *a)* J/ψ and *b)* K^* mesons from $B \to J/\psi K^*$ decay.

yields $\alpha = -1.17 \pm 0.17$. This implies that J/ψ mesons from the decay $B \to J/\psi K^*$, which dominate the rate in the high-momentum region, are predominantly produced with helicity zero. However, a similar analysis performed by CLEO [32] results in $\alpha = -0.25 \pm 0.43$ (see Fig.8b). Although the CLEO value is marginally consistent with the ARGUS result, it leads instead to the conclusion that the fraction of the (0,0) state in $B \to J/\psi K^*$ decays is small.

As a further demonstration that the J/ψ mesons produced in $B \to J/\psi K^*$ decays are longitudinally polarized, ARGUS has studied the distributions of the helicity angles for the J/ψ and K^* decays in 12 events containing B mesons reconstructed in these two-body channels. The corresponding distributions are shown in figure 9.

Both are in good agreement with the expectation for a $J/\psi K^*$ system in a (0,0) state. The best fit corresponds to a pure (0,0) helicity state, a CP eigenstate, with a lower limit of $\Gamma_{00}/\Gamma_{tot} > 0.78$ at the 95% CL. Consequently the dilution of CP asymmetry is small, and the sensitivity of the decay $B^0 \to J/\psi K^{*0}$ with $K^{*0} \to K^0_S \pi^0$ in searches for CP violation will be comparable to that for $B^0 \to J/\psi K^0_S$.

Observation of the decay $B^\pm \to \chi_{c1} K^\pm$, dominance of the helicity (0,0) state in the decay $B^0 \to J/\psi K^{0*}$, and larger theoretical estimates of f_B [33] suggest that the luminosity required to observe CP violation could be substantially smaller than conservative estimates used in B factory design studies [30]. This is a good news for a B factory.

Table 4: Inclusive B meson branching ratios.

Decay mode	BR (%) ARGUS	BR (%) CLEO
$B \to D^{\mp} X$	$23 \pm 4 \pm 5$	$25 \pm 4 \pm 3$
$B \to D^0 X$	$46 \pm 6 \pm 7$	$55 \pm 4 \pm 8$
$B \to D_S X$	10.8 ± 3.5	$11.1 \pm 2.2 \pm 4.4$
$B \to$ "Λ_c" X	$7.6 \pm 1.4 \pm 1.8$	6.4 ± 1.1
$B \to$ "$c\bar{c}$" X	$4 \cdot (1.07 \pm 0.16 \pm 0.22)$	$4 \cdot (1.12 \pm 0.18)$
Σ	91.7 ± 12.0	102.0 ± 11.4

2.4 Charm Counting in B Decays

The decays of B mesons are dominated by $b \to c$ transitions. The latest ARGUS and CLEO [12] yields for stable charmed particles and charmonium states are summarized in table 4. The sum over all inclusive channels is lower than the expected value of 1.15 c quark per B decay, where one c quark comes from $b \to cW^-$ transitions and an additional 15% originates from charm production in the fragmentation of $W^- \to c\bar{s}$. Contributions of about 2% from $b \to uW^-$ transitions (see discussion below) and an estimated 1-2% from loop-induced $b \to s$ transitions [34] can be neglected at the present level of accuracy. If one uses the PDG values for the D meson branching ratios [22], instead of the MARK III results, the charm yield in B decays increases to 1.02 ± 0.12 (ARGUS) and 1.14 ± 0.13 (CLEO). This is closer to expectation. However, the present level of accuracy does not allow one to exclude the possibility of a sizable fraction of non-charm B decays (or non-$B\overline{B}$ $\Upsilon(4S)$ decays) even at 20% level.

3. Semileptonic B Decays

Semileptonic B decays are best understood both theoretically and experimentally. Their study provides at present the best method for determining the values of CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$.

3.1 Inclusive Lepton Spectrum

The inclusive semileptonic branching ratio of B meson has been determined quite precisely. The latest results obtained at $\Upsilon(4S)$ energies are summarized in table 5. The average branching ratio $BR(B \to lX) = (10.3 \pm 0.2)\%$ [1] is too small to be understood in a straight-forward way in the spectator model where a branching ratio of 12-14% is predicted [36]. Measurements at the Z^0 peak, which actually represent average semileptonic branching ratios for an unknown mixture of b-flavoured hadrons, yield similar values of less than 11% [3] (except for L3).

Table 5: Recent measurements of B meson semileptonic branching ratio at $\Upsilon(4S)$ energy.

	$BR(B \to X\ell^-\bar{\nu})$ (%)
ARGUS	$10.2 \pm 0.4 \pm 0.2$
CLEO	$10.5 \pm 0.3 \pm 0.4$
CLEO (ll)	$10.6 \pm 0.5 \pm 0.6$
CUSB	$10.0 \pm 0.4 \pm 0.3$
X Ball	$12.0 \pm 0.5 \pm 0.7$
Average	10.3 ± 0.2

Since the low momentum part of the lepton spectrum is dominated by leptons from charm decays, only the energetic region can effectively be used for the determination of the B meson semileptonic branching ratio. Extrapolation to the whole momentum interval is usually performed using the ACM model [37] (as was done in table 5). One possible explanation of the discrepancy between experiment and theory could be an under-estimation of the contribution from soft leptons. Semileptonic B decays into baryons could be a source of soft leptons. However, ARGUS has demonstrated that this source cannot solve the problem [38].

In the recent CLEO analysis based on the

[1] This value represents semileptonic branching ratio of the mixture of B^0 and B^+ mesons. Using tagged samples of B mesons CLEO has measured $BR(\overline{B^0} \to X^+\ell^-\bar{\nu}) = 10.4 \pm 2.2^{+1.0}_{-1.1}\%$ [35].

ISGW model [39] the fraction of $D^{**}l\nu$ final state is allowed to vary. This leads to a larger semileptonic branching ratio of $(11.2 \pm 0.3 \pm 0.4)\%$ [35]. However, such a procedure is almost equivalent to an arbitrary change of the shape of the lepton spectrum and therefore does not add much to our understanding of the problem. The problem could be solved by invoking unexpectedly large nonspectator effects at about the 20% level. A recent discussion of this possibility can be found in [36]. One could also question the validity of the spectator model estimates for a process which is dominated by a few exclusive channels [40]. Semileptonic B decays into D and D^* comprise about 65% of the inclusive branching ratio.

3.2 Decays $B \to D^* l\nu$

ARGUS pioneered the measurement of $\overline{B^0} \to D^{*+}l^-\bar{\nu}$ decay using a missing mass technique [41]. The recoil mass squared against D^*l combination, M^2_{recoil}, is calculated from the D^{*+} and l^- momenta, neglecting the small momentum of the B meson in the laboratory frame:

$$M^2_{recoil} = (E_{B^-} - E_{D^*} - E_{l^-})^2 - (\vec{p}_{D^*} + \vec{p}_{l^-})^2.$$

The resolution on M^2_{recoil} is sufficient to achieve a good separation from backgrounds.

Recently the ARGUS collaboration has extended the M^2_{recoil} technique to $B^- \to D^{*0}l^-\bar{\nu}$ decays, where D^{*0} meson is reconstructed in the decay chain $D^0\gamma$. The main difficulty for D^{*0} reconstruction arises from the large combinatorial background created by many soft photons from π^0 decays. In order to reduce this background to a manageable level no more than 5 photons with an energy larger than 80 MeV are allowed in the event. In addition photons from π^0 decays are removed by eliminating those photon pairs whose invariant mass lies within ± 50 MeV/c^2 of the nominal π^0 mass.

The distribution of $D^0\gamma$ invariant mass after subtraction of the D^0 sideband contribution is shown in figure 10 for $|M^2_{recoil}| < 1$ GeV^2/c^4. There is a prominent peak near the mass of the D^{*0} meson. The shoulder on the low-mass side of the peak is a contribution from the decay $D^{*0} \to D^0\pi^0$, followed by $\pi^0 \to \gamma\gamma$. If one of the two photons is used to make an entry in the $D^0\gamma$ mass distribution, the corresponding D^{*0} signal

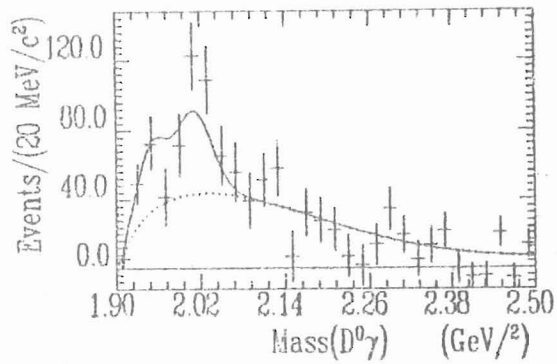

Figure 10: $D^0\gamma$ mass.

is shifted to lower masses. This photon is not rejected by the anti-π^0 cut because the second photon typically has an energy below $80MeV$ and therefore is not used in the analysis. The dotted line in the figure 10 represents the background due to uncorrelated $D^0\gamma$ combinations normalized to the number of D^0 mesons observed in events with leptons.

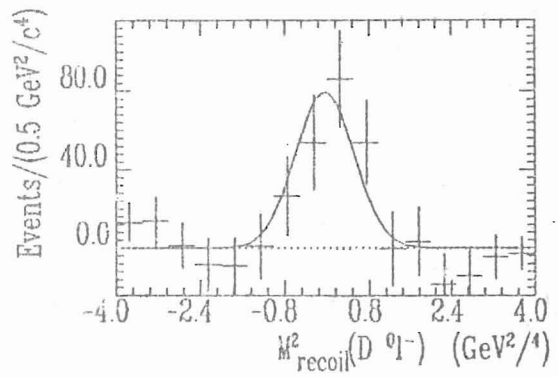

Figure 11: $M^2_{recoil}(D^{*0}l^-)$ distribution after subtraction of all backgrounds.

The observed peak in figure 10 also includes a possible contribution from cascade decay $B \to D^{**}\ell\nu$ followed by $D^{**} \to D^{*0}\pi$. Since the latter is not measured, its contribution is evaluated from the data by examining the distribution of the signal in recoil mass squared shown in figure 11. The solid line is the result of a fit to the recoil mass distribution using the sum of two Gaussians, corresponding to the contributions from the signal channel and the cascade decays. The signal for $B^- \to D^{*0}\ell^-\bar{\nu}$ is deter-

Table 6: Branching ratios for $\overline{B^0} \to D^{*+} l^- \bar{\nu}$ and $B^- \to D^{*0} l^- \bar{\nu}$ decays.

Decay mode	$BR(\%)$			
	ARGUS	CLEO	XBall	Average
$\overline{B^0} \to D^{*+} \ell^- \bar{\nu}$	$5.4 \pm 0.9 \pm 1.3$	$4.6 \pm 0.5 \pm 0.7$	---	4.8 ± 1.0
$B^- \to D^{*0} \ell^- \bar{\nu}$	$5.1 \pm 1.3 \pm 1.2$	---	8.0 ± 3.4	5.7 ± 1.6

Table 7: Determination of $|V_{cb}|$ from $B \to D^* l\nu$ decay.

Model	$\lvert V_{cb}\rvert$
ESW [44]	0.043 ± 0.005
KS [45]	0.039 ± 0.004
GISW [39]	0.040 ± 0.004
KP [46]	0.036 ± 0.004

mined to be 224 ± 54 events, which corresponds to

$$BR(B^- \to D^{*0} l^- \bar{\nu}) = 5.8 \pm 1.4 \pm 1.3\%.$$

The presently available experimental data on $BR(B \to D^* l\nu)$ are summarized in table 6, including an indirect measurement by the Crystal Ball collaboration [42].

Theoretical models predict partial widths of exclusive semileptonic B decays in terms of CKM matrix elements. To transform measured branching ratios into decay rates we assume $\tau_{B^0} = \tau_{B^+} = (1.28 \pm 0.06) \times 10^{-12}$ sec [3]. In order to minimize effects due to possible differences between τ_{B^0} and τ_{B^+}, we use the average branching ratio:

$$BR(B \to D^* l\nu) = \frac{1}{2}\{BR(B^- \to D^{*0} \ell^- \bar{\nu}) + BR(\overline{B}^0 \to D^{*+} \ell^- \bar{\nu})\} = 5.0 \pm 1.0\%.$$

Table 7 lists the values of $|V_{cb}|$ derived from this result using different theoretical models. The small scattering of the values obtained using different models does not demonstrate that the model dependence is small, since models which do not describe the experimental data (especially Γ_L/Γ_T [41,43]) have already been discarded.

3.3 Determination of $|V_{cb}|$ in HQET

HQET has attracted large interest during the last three years [26,47]. There is some hope that this approach can provide a basis for a model independent description of beauty, and perhaps even charmed hadrons.

The possibility of $|V_{cb}|$ extraction from the decay $B \to D^* l\nu$ in the infinite quark mass limit was first discussed by Voloshin and Shifman [47]. They have shown that the decay rate for $B \to D^* l\nu$ when the momentum of the D^* is small can be found in a model independent way. Corrections to this prediction are of the order of $\mu^2/m_c{}^2 \sim 5\%$, where μ is a characteristic momentum of quarks in the meson. HQET [26] generalizes this result. In this approach, the decay width over the full Dalitz plot depends only on the $|V_{cb}|$ matrix element and a single universal function, the Isgur-Wise function $\xi(y)$, where $y = v \cdot v'$ is a product of the four-velocities of the B and D^* mesons. The product $|V_{cb}|\xi(1)$ can be determined by extrapolation from the full momentum interval [48].

For the determination of $|V_{cb}|$, the y distributions of D^{*+} and D^{*0} mesons from $\overline{B}^0 \to D^{*+} \ell^- \bar{\nu}$ and $B^- \to D^{*0} \ell^- \bar{\nu}$ decays have been investigated. The latter channel is particularly suitable since the reconstruction efficiency for the D^{*0} is practically independent of momentum, in contrast to the case for the D^{*+} in the decay $\overline{B}^0 \to D^{*+} \ell^- \bar{\nu}$. Figure 12 shows $|V_{cb}|\xi(y)$ extracted from the ARGUS and CLEO data [48,49]. The shape of the Isgur-Wise function is not fixed by theory, but is equal to one at the zero recoil point $y = 1$. The fit with a linear parameterization for the Isgur-Wise function finds $|V_{cb}| = 0.044 \pm 0.007$ [48] and $|V_{cb}| = 0.043 \pm 0.009$ [49] for B^0 and B^+ respectively. Similar results are obtained for $|V_{cb}|$ under different parameterizations for the Isgur-Wise function, such as a single-pole model or an exponential dependence.

3.4 Decays $B \to Dl\nu$

Exclusive $B \to Dl\nu$ decays are more difficult

Table 8: Branching ratios for $B \to Dl\nu$ and $B \to D^* l\nu$ decays.

	CLEO	ARGUS
BR $(B^- \to D^0 \ell^- \bar{\nu})$	$1.6 \pm 0.6 \pm 0.3\%$	$1.5 \pm 0.5 \pm 0.3\%$
BR $(\overline{B^0} \to D^+ \ell^- \bar{\nu})$	$1.8 \pm 0.6 \pm 0.3\%$	$1.5 \pm 0.5 \pm 0.3\%$
BR $(B^- \to D^{*0} \ell^- \bar{\nu})$	$4.1 \pm 0.8^{+0.6}_{-0.9}\%$	$4.4 \pm 0.6 \pm 0.5\%$
BR $(\overline{B^0} \to D^{*+} \ell^- \bar{\nu})$	$4.6 \pm 0.5 \pm 0.7\%$	$4.4 \pm 0.6 \pm 0.5\%$
$\mathrm{BR}(B \to D^* \ell\bar{\nu})/\mathrm{BR}(B \to D\ell\bar{\nu})$	$2.6^{+1.1+1.0}_{-0.6-0.8}$	$2.9^{+1.3+0.5}_{-0.6-0.3}$
$\tau_+/\tau_0 \cdot (f_+/f_0)$	$0.89 \pm 0.19 \pm 0.13$	$1.00 \pm 0.18 \pm 0.12$

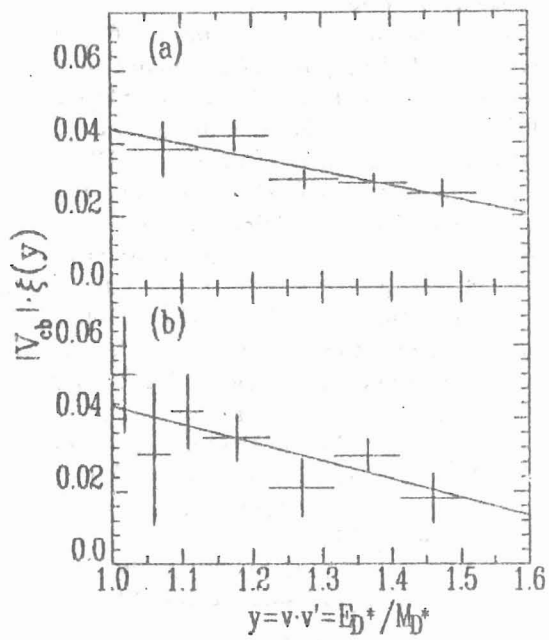

Figure 12: Distributions of $|V_{cb}|\xi(y)$ for (a) $\overline{B^0} \to D^{*+}\ell^-\bar{\nu}$ and (b) $B^- \to D^{*0}\ell^-\bar{\nu}$ decays. The solid lines show the fit results.

to detect experimentally than $B \to D^* l\nu$ decays because of a large combinatorial background and feed-down from the dominant $B \to D^* l\nu$ decays. Nevertheless, they have been observed by ARGUS [50] and CLEO [51]. The D^* contributions peak at a slightly positive values of $M^2_{recoil}(Dl)$ enabling simultaneous indirect measurement of the branching ratios for $B \to D^* l\nu$ decays. The results are presented in table 8.

Unlike D meson decays, vector D^* mesons are produced about 3 times more frequently in semileptonic B decays than pseudoscalar D mesons. This agrees with the expectations from naive spin counting. A lifetime ratio for neutral and charged B mesons can be determined from the ratio of branching ratios of $B^- \to D^0\ell^-\bar{\nu}$ and $B^0 \to D^-\ell^+\nu$ decays. Averaging the values of τ_{B^0}/τ_{B^+} from table 8 with that derived from the study of $B \to D^* l\nu$ decays with fully reconstructed D^* mesons, one finds:

$$\left(\frac{f_0}{f_+}\right)\frac{\tau_{B^0}}{\tau_{B^+}} = 1.00 \pm 0.14$$

This result is in agreement with the theoretical expectations of almost equal lifetimes of charged and neutral B mesons. It is supported by the direct ALEPH measurements [3]:

$$\tau_{B^0} = 1.42^{+0.52+0.18}_{-0.48-0.40}\ psec,$$

$$\tau_{B^+} = 1.35^{+0.42+0.26}_{-0.46-0.40}\ psec.$$

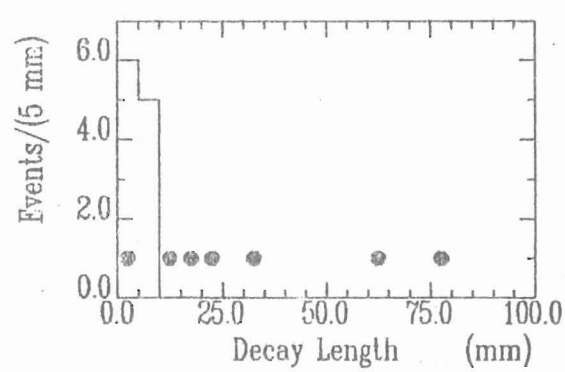

Figure 13: Decay length distributions for neutral (histogram) and charged (points) B mesons (E653).

However, measurements of B^0 and B^+ lifetimes in emulsion by the E653 collaboration [52] illustrated in Fig. 13 give quite different values:

$$\tau_{B^0} = 0.6^{+0.23}_{-0.15}\ psec\ and\ \tau_{B^+} = 2.4^{+1.5}_{-0.8}\ psec.$$

The partial width of a semileptonic B decay to a pseudoscalar meson depends only on one non-negligible form factor and therefore can be reliably calculated. Again using the average branching ratio:

$$BR(B \to Dl\nu) = \frac{1}{2}[BR(B^- \to D^0\ell^-\overline{\nu}) + BR(B^0 \to D^-\ell^+\nu)] = 1.6 \pm 0.4\%$$

one derives the values of $|V_{cb}|$ listed in table 9.

Table 9: Determination of $|V_{cb}|$ from $B \to Dl\nu$ decay.

Model	$\lvert V_{cb}\rvert$
BSW [44]	0.040 ± 0.006
KS [45]	0.039 ± 0.005
GISW [39]	0.034 ± 0.005
KP [46]	0.038 ± 0.005

3.5 Semileptonic $b \to u$ Decays

The existence of charmless semileptonic decays is reliably established. ARGUS [53] and CLEO [54] have observed leptons above the kinematic limit for the $b \to cl\nu$ transition. Both collaborations have checked that the observed excess cannot be explained by other processes including hypothetical non-$B\overline{B}$ decays of $\Upsilon(4S)$.

In order to obtain additional confirmation that the excess of high momentum leptons indeed originates from $b \to ul^-\bar{\nu}$ transitions, ARGUS has made a systematic attempt to completely reconstruct the signal events. As a result of this search one fully reconstructed event was found [55], consistent with expectation. In this event the $\Upsilon(4S)$ decays into a pair of $\overline{B^0}$ mesons, indicating that one B^0 meson has oscillated into a $\overline{B^0}$. Thus, the event simultaneously demonstrates the existence of $b \to u$ transitions, and $B^0\overline{B^0}$ mixing. One $\overline{B^0}$ was reconstructed in the mode $\overline{B^0} \to D^{*+}\rho^-$. The second $\overline{B^0}$ meson was seen in the channel $\overline{B^0} \to \pi^+\mu^-\bar{\nu}$, representing the first direct observation of a $b \to u$ transition. Relevant kinematic quantities for this event agree nicely with expected values.

Having explicitly shown that $b \to ul^-\bar{\nu}$ transitions are responsible for the excess of leptons with momenta above the endpoint for $b \to cl^-\bar{\nu}$ transitions, the strength of the $b \to u$ coupling can be inferred from the inclusive spectra. However, using only a narrow portion of the full momentum interval, the extracted value for $|V_{ub}|$ is quite model dependent. Using the ACM model [37] ARGUS [55] and CLEO [54] derived $|V_{ub}|/|V_{cb}|$ values of 0.11 ± 0.01 and 0.12 ± 0.2, respectively. For the latter, only the CLEO measurement in the momentum interval 2.4-2.6GeV/c has been used. Over the wider range 2.2-2.6GeV/c their result is not statistically significant and relies heavily on a precise knowledge of the large $b \to cl^-\bar{\nu}$ contribution, which has to be subtracted. Other models lead to a wide range of values for $|V_{ub}|/|V_{cb}|$ from 0.1 to 0.2 [101].

Since the measurement of the lepton spectrum from $b \to ul^-\bar{\nu}$ transitions in a wider momentum interval seems to be hopeless at present, ARGUS made a first attempt to reconstruct exclusive $B^+ \to \rho^0 l^+\nu$ decay in order to constrain theory [57]. To achieve sufficient background suppression ARGUS applies all possible cuts using the decay kinematics and then compares the result with the Monte Carlo prediction for the $b \to cl^-\bar{\nu}$ transition. In the $\pi^+\pi^-$ invariant mass distribution they observe an excess of 31 ± 10 ρ mesons which can be attributed to the decay $B^+ \to \rho^0 l^+\nu$. This corresponds to the branching ratio of $(1.13 \pm 0.36 \pm 0.26) \times 10^{-3}$. Obviously this analysis relies heavily on the Monte Carlo. ARGUS has checked that the simulation well describes other distributions in the data.

4. $B^0\overline{B^0}$ Oscillations

The observation of unexpectedly large $B_d^0\bar{B}_d^0$ mixing was first reported by ARGUS [58] and confirmed by CLEO [59]. Recently ARGUS and CLEO [35] updated their results on $B^0\overline{B^0}$ mixing. The mass difference ΔM between the CP eigenstates in the B system is proportional to $|V_{td}|^2 m_t^2$. The value of ΔM can be obtained from the measurements of the experimentally accessible mixing parameter r which is connected to ΔM by

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

$B^0\overline{B^0}$ mixing manifests itself in the production of B^0B^0 or $\overline{B}^0\overline{B}^0$ pairs. Due to the low efficiency

for the reconstruction of B mesons a partial reconstruction is usually used which is sufficient to tag the flavour of both B mesons.

Table 10: Dilepton rates and a mixing parameter r.

	ARGUS	CLEO
$N_{\ell^+\ell^+}$	48.1 ± 14.1	32.5 ± 9.2
$N_{\ell^+\ell^-}$	505 ± 27	426 ± 22
r	0.21 ± 0.07	0.17 ± 0.07

At present 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 $\overline{B^0}$ mesons produce only l^-. $B^0\overline{B^0}$ mixing leads to like-sign lepton pairs. The ARGUS [60] and CLEO [35] dilepton rates after background subtraction are listed in table 10. In this method the number of like-sign lepton pairs from charged B decays should be subtracted. In order to estimate this number we take

$$\frac{f_+\tau_{B^+}}{f_0\tau_{B^0}} = 1.0 \pm 0.14$$

and assume $\tau_{B^0}/\tau_{B^+} = 1.0 \pm 0.1$ [61]. This leads to $r = 0.19 \pm 0.05$.

Table 11: The number of $B^0\ell^+$ and $B^0\ell^-$ events and the mixing parameter r.

	ARGUS	CLEO
$N_{B^0\ell^+}$	6.7 ± 3.4	1.9 ± 3.1
$N_{B^0\ell^-}$	29.1 ± 5.8	20.2 ± 6.3
r	0.23 ± 0.12	0.09 ± 0.16

In a second method one B^0 meson is reconstructed using the decay $B^0 \to D^{*-}l^+\nu$ while the recoil B is again tagged with the lepton charge. Table 11 gives the number of such events observed by ARGUS [60] and CLEO [35]. This method yields $r = 0.18 \pm 0.10$. Combining the two results on r one finds:

$$r = 0.184 \pm 0.043,$$

$$\chi = \frac{r}{1+r} = 0.155 \pm 0.031,$$

$$x = \Delta M \cdot \tau_b = 0.67 \pm 0.10$$

Using this result, together with the estimate $B_B^{\frac{1}{2}} f_B = (140 \pm 40)\ MeV$ and $m_t < 200\ GeV/c^2$ from the analysis of electroweak radiative corrections to M_W/M_Z, one obtains

$$0.008 < |V_{td}| < 0.021.$$

The upper limit on $|V_{td}|$, inferred by invoking unitarity of the CKM matrix, depends on the model dependent ratio $|V_{ub}|/|V_{cb}|$. For the quoted value, we use $|V_{ub}|/|V_{cb}| < 0.2$ [53,54,55].

The SM with three generations predicts a large rate for $B_s^0\overline{B_s^0}$ mixing:

$$\frac{x_s}{x_d} \approx \frac{|V_{ts}|^2}{|V_{td}|^2} > 5.$$

Table 12: $B^0\overline{B^0}$ mixing at high energies.

	$\chi = f_d\chi_d + f_s\chi_s$
LEP (dileptons)	0.143 ± 0.023
UA1	0.145 ± 0.038
CDF	0.176 ± 0.050
Average	0.148 ± 0.018

Thus a determination of x_s would be a crucial test. Information on x_s can be obtained from the measurements of $B\bar{B}$ mixing at high energies, where a mixture of all beauty hadrons, including B_d^0 and B_s^0 mesons, is produced. Usually one assumes that $\chi = 0.375\chi_d + 0.15\chi_s$, where χ_d and χ_s represent the mixing parameters for B_d^0 and B_s^0 mesons respectively.

The latest measurements of $B\bar{B}$ mixing at high energies [3] are summarized in table 12. Combining these results with those from ARGUS and CLEO on χ_d, one obtains a small allowed region in the χ_s-χ_d plane (see figure 14), which is consistent with the practically complete $B_s^0\overline{B_s^0}$ mixing predicted by the SM.

5. A Search for $b \to s$ Transitions

The transitions $b \to s\gamma$ and $b \to sg$ can also provide information on the $|V_{ts}|$ matrix element,

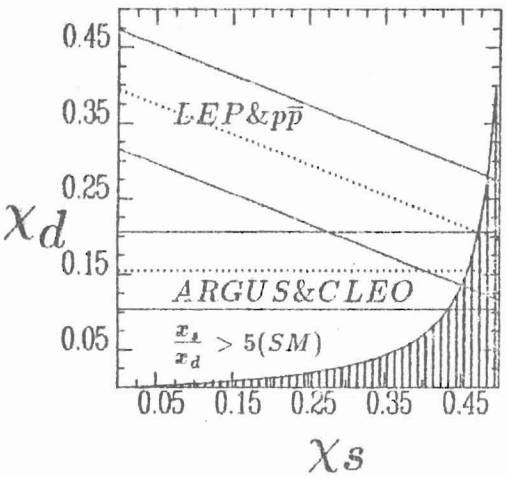

Figure 14: 90% CL limits on the mixing parameters χ_d and χ_s. The hatched area shows the allowed region $x_s/x_d > 5$ predicted by the SM.

as can be seen in Fig.15. Recently CLEO [62] and XBall [63] have obtained new limits on $b \to s\gamma$ transitions, which are collected in table 13.

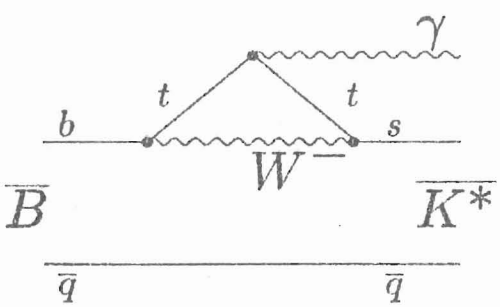

Figure 15: One of the diagrams for $B \to K^*\gamma$ decay.

Theoretical estimates for exclusive channels are model dependent. For example, predictions of $Br(B^0 \to K^{*0}(892)\gamma)$ vary from 4.5% to 40% [65]. The inclusive branching ratio is estimated with less ambiguity to be about 4×10^{-4} for $m_t = 120\ GeV/c^2$ [66,65]. The photon energy spectrum in B decays is shown in Fig.16 [62]. More than 70% of photons from $b \to s\gamma$ transitions should populate the region 2.2-2.7GeV [62]. The excess in this region is not statistically significant and CLEO quotes an upper limit listed

Table 13: Upper limits on electromagnetic penguin-mediated B decays.

Final state	$BR \cdot 10^4$ (90% CL) CLEO [62]	ARGUS [64]	XBALL [63]
$K^{*0}(892)\gamma$	0.92	4.2	15
$K^{*+}(892)\gamma$	3.7	5.2	
$K_1^0(1270)\gamma$	5.5	78	
$K_1^+(1270)\gamma$	11	66	
$K_1^0(1400)\gamma$	5.4	48	16
$K_1^+(1400)\gamma$	4.8	20	
$K_2^{*0}(1430)\gamma$	1.3	4.4	
$K_2^{*+}(1430)\gamma$	3.7	13	
$K_3^{*0}(1780)\gamma$	7.6	110	12
$K_3^{*+}(1780)\gamma$	14	50	
$b \to s\gamma$	8.4		28

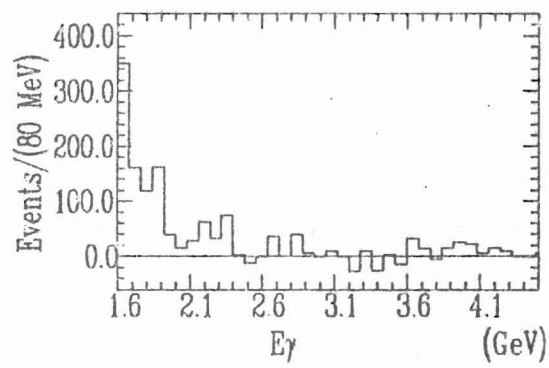

Figure 16: Photon energy spectrum in B decays (CLEO).

in table 13. The experimental upper limits on penguin-mediated electromagnetic B decays are already very close to the SM predictions and constrain theories which go beyond the SM [65], such as models with light charged Higgs particles or left-right symmetric models.

6. Unitarity Triangle

Unitarity of the CKM matrix requires

$$V_{ub}^* + V_{td} - \sin\theta_C V_{cb} \approx 0.$$

Based on the LEP results for the Z^0, we know

that the three elements of this equation form a closed triangle in the complex plane, since there are only 3 generations of quarks and leptons.

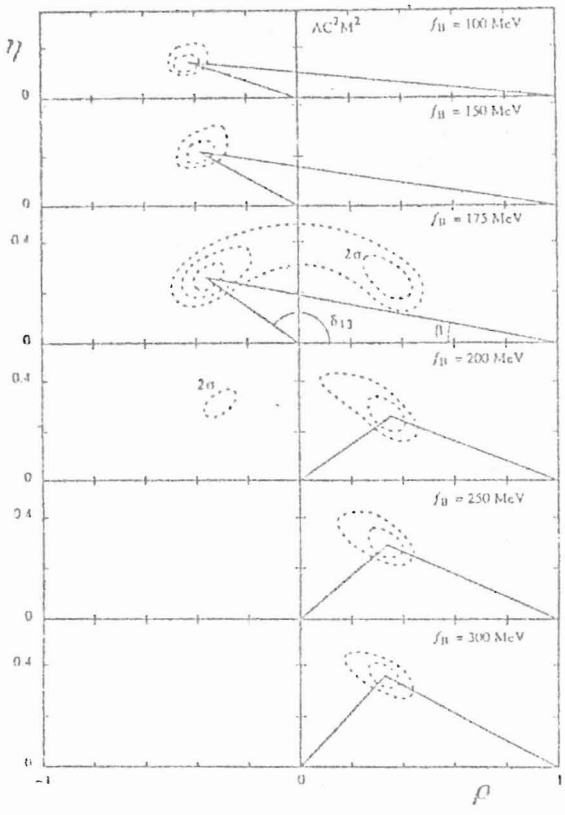

Figure 17: Unitarity triangle.

Constraints on the sides of the unitarity triangle come from the measurements of $B^0\overline{B^0}$ mixing (V_{td}/V_{cb}), charmless semileptonic B decays (V_{ub}/V_{cb}), and CP violation in K^0 decays. These constraints depend on the t quark mass, the decay constant of the B meson, and the bag parameter B_K. The shape of the unitarity triangle would be practically fixed, or even overconstrained, if these parameters were known precisely. Unfortunately this is not the case. Taking $B_K = 0.8 \pm 0.1$, $|V_{ub}|/|V_{cb}| = 0.10 \pm 0.008$ (derived using ACM model [37]), and $m_t = 137 \pm 39 GeV/c^2$ from a radiative correction analysis, Schmidtler and Schubert [67] performed a fit for different fixed values of f_B. The results of this fit are shown in Fig.17 where ρ and η are the Wolfenstein parameters [68] defined using the PDG parameterization of the CKM matrix [22] as

$$\rho = s_{13} cos\delta_{13}/s_{12}s_{23},$$

$$\eta = s_{13} sin\delta_{13}/s_{12}s_{23}.$$

The vertex of the triangle lies in the second quadrant for the small values of f_B preferred by theorists for a long time. However, for the large values of f_B obtained by recent lattice calculations [33] the vertex moves into the first quadrant. This would simplify a study of CP violation at B factories [30]. Values of $|V_{ub}|/|V_{cb}|$ derived using other models lead to somewhat different allowed regions in the $\rho - \eta$ plane. However, the general pattern remains unchanged.

7. Beauty Summary

New CLEO data do not support their earlier claim for observation of non-$B\overline{B}$ decays of $\Upsilon(4S)$, but provide instead evidence for fast J/ψ production in continuum. About 18% of nonleptonic B decays have been measured. The decays $B \to D_S^{(*)} D^{(*)}$ constitute about one third of these. The observation of the decay $B \to \chi_{c1} K$ and the dominance of the CP eigenstate in the decay $B^0 \to J/\psi K^{0*}$ will simplify the study of CP violation at B factories.

The analysis of the semileptonic B decays into D^{*+} and D^{*0} using HQET leads to $|V_{cb}| = 0.43 \pm 0.005$. Similar values are obtained from the studies of inclusive semileptonic B decays and B decays into $D\ell\nu$. From the measurements of charmless semileptonic B decays $|V_{ub}|/|V_{cb}| = 0.11 \pm 0.01$ can be derived using the spectator model [37]. Other models lead to $|V_{ub}|/|V_{cb}|$ in the range from 0.1 to 0.2.

The ARGUS and CLEO updates on $B^0\overline{B^0}$ mixing confirm the original observation and give

$$r = 0.184 \pm 0.043,$$

$$\chi = 0.155 \pm 0.031,$$

$$x = 0.67 \pm 0.10.$$

Measurements at high energies demonstrate that $B_s^0\overline{B_s^0}$ mixing is consistent with being complete in accordance with the theoretical expectations. However, systematic uncertainties do not allow

an accurate estimate of x_t. New CLEO limits on $b \to s\gamma$ transitions are very close to the SM predictions.

Our knowledge of the fundamental parameters of the SM describing quark mixing is limited not by the experimental errors but by the theoretical uncertainties in the estimation of hadronic interactions and the unknown top quark mass. Recent developments in HQET, lattice calculations and other theoretical approaches offer some future prospect for a model independent extraction of these parameters from the experimental data.

CHARM

1. Charmonium spectroscopy in $p\bar{p}$ annihilation

Our knowledge of charmonium spectroscopy comes mainly from e^+e^- colliders, which provide a clean initial state and a large signal to background ratio. However, only vector states can be produced in e^+e^- annihilation. Many other states can be reached by vector state decays, but some are hard to observe. For example, up to now there is no convincing evidence for the 1^1P_1 state.

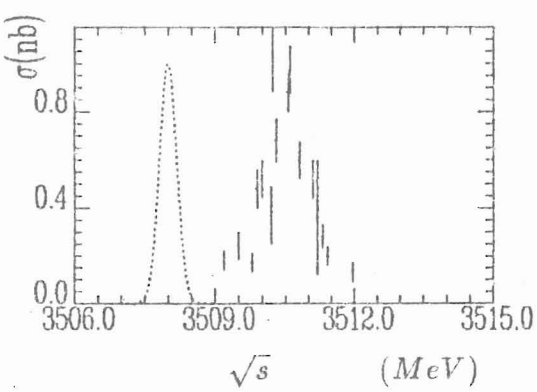

Figure 18: Measured cross-section at the χ_{c1} resonance. Dotted curve shows the experimental resolution.

On the other hand all states can be produced in $p\bar{p}$ annihilation. The $R704$ collaboration at the ISR pioneered this approach [69] and achieved a much better mass resolution than at e^+e^- machines. Even more impressive results have been obtained recently by the E760 experiment at Fermilab [70]. By stochastic cooling of antiprotons they achieved $\sigma_p/p \approx 2 \times 10^{-4}$, which translates into a mass resolution of about $0.25 MeV/c^2$. This resolution is much smaller than the intrinsic widths of χ_c states (see Fig. 18). E760 has already considerably improved the accuracy of the χ_c parameters, including a first determination of the width of the χ_{c1} resonance $\Gamma(\chi_{c1}) = (0.88 \pm 0.11 \pm 0.08) MeV$ [70]. However, the most interesting results are expected in the future. They anticipate observing the 1^1P_1 state, for which a recent analysis predicts [71]

$$3536 MeV/c^2 < M(1^1P_1) < 3560.7 MeV/c^2,$$

and should be able to make more precise measurements of other states.

2. D^* Decays

There is a long standing problem in charm spectroscopy. The branching ratio for the decay $D^{*+} \to D^+\gamma$ was measured to be $(18 \pm 4)\%$ [22] while theory predicts only about $3\% - 5\%$ [72,73]. This discrepancy has stimulated considerable speculation, including a conjecture of an anomalous magnetic moment of the charm quark [72]. Recently CLEO II has searched for this decay [74] using their excellent electromagnetic calorimeter. They find no evidence for this mode (see Fig. 19), while observing a beautiful signal in $D^+\pi^0$ channel (see. Fig. 20).

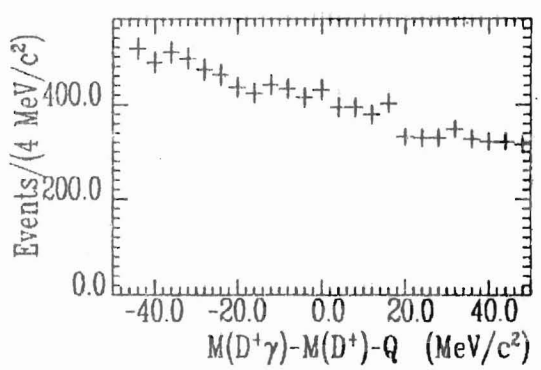

Figure 19: Mass difference distribution for the $D^+\gamma$ mode.

The upper limit obtained, $BR(D^{*+} \to D^+\gamma) < 8.0\%$, agrees comfortably with the theoretical expectations. The decrease in radiative branching

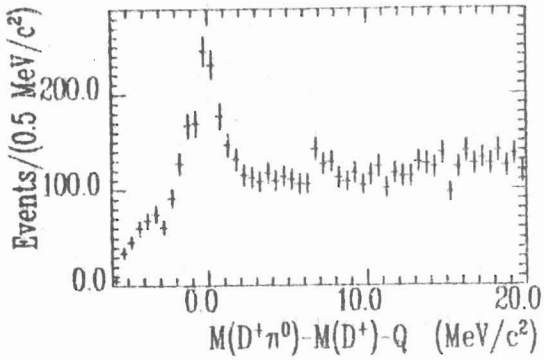

Figure 20: Mass difference distribution for the $D^+\pi^0$ mode.

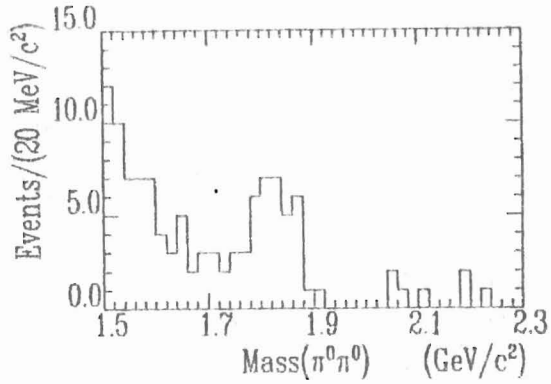

Figure 21: $\pi^0\pi^0$ mass distribution from D^{*+} region.

Table 14: D^* branching ratios in (%).

Mode	CLEO	PDG
$D^0\gamma$	$43.0 \pm 3.7 \pm 4.2$	45 ± 6
$D^0\pi^0$	$57.0 \pm 3.7 \pm 4.2$	55 ± 6
$D^+\gamma$	$3.8 \pm 2.8 \pm 2.0$	18 ± 4
$D^+\pi^0$	$30.9 \pm 1.6 \pm 4.4$	27.2 ± 2.5
$D^0\pi^+$	$65.3 \pm 2.4 \pm 6.0$	55 ± 4

ratio is compensated by a larger rate for $D^{*+} \to D^0\pi^+$ (see table 14). Other channels are in a good agreement with previous measurements. The decay $D^{*+} \to D^0\pi^+$ is very often used for charm tagging and therefore the new branching ratio will influence many published results. However, B meson decays into D^{*+} are not affected much, since lower D^0 branching ratios are preferred by the PDG [22] and by recent measurements at LEP [3].

3. Cabibbo-Suppressed D Decays

More than 30 new measurements of Cabibbo-suppressed D decays have been performed recently. CLEO [75] observed D^0 decay into $\pi^0\pi^0$ (see Fig. 21) with a branching ratio of $(0.11 \pm 0.04)\%$. Thus D^0 decays more frequently to two kaons than to two pions [75]:

$$\frac{BR(D^0 \to K^+K^- \; or \; K^0\overline{K}^0)}{BR(D^0 \to \pi^+\pi^- \; or \; \pi^0\pi^0)} = 2 \pm 0.4$$

while theory predicts approximately equal rates [76]. This is a long standing problem [76]. However, in four prong Cabibbo-suppressed decays the kaon fraction is much smaller [77,78]. For the ratio

$$\frac{BR(D^0 \to K^+K^-\pi^+\pi^-)}{BR(D^0 \to \pi^+\pi^-\pi^+\pi^-)}$$

E691 and CLEO obtained

$$\frac{0.26^{+0.07}_{-0.06} \pm 0.05}{0.87 \pm 0.16 \pm 0.13}$$

and

$$\frac{0.24 \pm 0.08}{0.80 \pm 0.14},$$

respectively. So on average kaon production in Cabibbo-suppressed D^0 decays is probably not enhanced.

ARGUS and CLEO [77] improved an upper limit on the the branching ratio for the double Cabibbo-suppressed decay $D^0 \to K^+\pi^-$ to 0.9% and 1.1% at 90% CL, respectively.

ARGUS has observed D^+ and D_s^+ decays into $K^{*+}\overline{K}^{*0}$ [79] (see Fig. 22). For the D^+ this is the strongest Cabibbo-suppressed decay seen so far, with $BR(D^+ \to K^{*+}\overline{K}^{*0}) = (2.6 \pm 0.8 \pm 0.7)\%$. This channel doubles the total known rate of Cabibbo-suppressed decays, which now amounts to about 5%. This value is almost twice as large as the naive spectator model estimate of 3%. On the other hand such an enhancement is natural if the large D^+ lifetime is due to interference between the $\bar{d}$ quark produced at the weak decay vertex and spectator $\bar{d}$ [76]. Such interference is responsible for reducing the fraction of

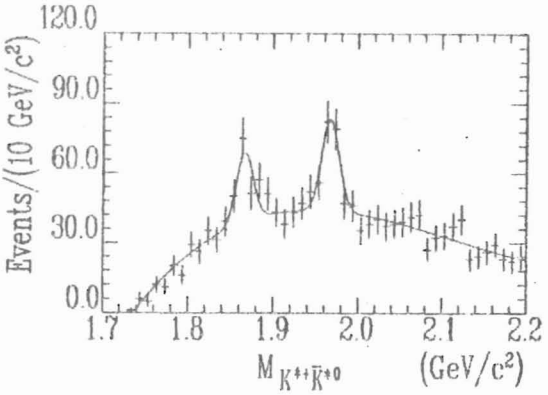

Figure 22: $K^{*+}\overline{K}^{*0}$ mass distribution.

Cabibbo-allowed D^+ decays, but does not exist in Cabibbo-suppressed decays.

4. D_s Decays

Contrary to D^0 and D^+ mesons,a majority of D_s^+ decays is not known yet. Some time ago the MARKII [80] collaboration claimed to observe D_s^+ decays into $\eta\pi^+$ and $\eta'\pi^+$ with very large branching ratios which would account for about a quarter of all D_s decays. Other experiments obtained smaller values or limits. New precise CLEO measurements lead to even smaller values for these branching ratios of $0.54\pm0.09\pm0.09$ and $1.20\pm0.15\pm0.18$ relative to $BR(D_s^+ \to \phi\pi^+)$ [81]. However, they are still larger than the theoretical predictions [85,23].

Recent measurements of D_s branching ratios [81,79,82] have tripled amount of known decays. They are listed in table 15 together with the previous measurements [22] and theoretical predictions. With $BR(D_s^+ \to \phi\pi^+) = 2.7\%$ the sum of known D_s branching ratios is now close to 50%.

5. Semileptonic Charm Decays

Semileptonic decays are simpler from the theoretical point of view than nonleptonic decays. However, all quark models failed to make correct prediction for D decays into $K^*l\nu$. This became evident when E691 observed a large K^* polarization and a small branching ratio for this decay in comparison with the decay $D \to \overline{K}l\nu$ [86]. Quark models predicted comparable branching ratios and approximately equal longitudinal (Γ_L) and transverse (Γ_T) widths [87].

Recently many new measurements of semileptonic charm decays have been performed. They are reviewed and compared with theoretical predictions in a minireview at this Conference by Potter[87]. Therefore we will be very brief on this interesting subject.

The decay $D \to \overline{K}l\nu$ depends on only one essential form factor and is well described by quark models and by QCD sum rules [87] (see table 16; more complete comparison with theory can be found in reference [87]). The recent lattice QCD calculations [89] give somewhat smaller value for this decay width than the experiment.

CLEO [90] and ARGUS have confirmed recently that indeed $\Gamma(D \to \overline{K}^*l\nu)$ is about two times smaller than $\Gamma(D \to \overline{K}l\nu)$ (see table 18). The width of the decay $D \to \overline{K}^*l\nu)$ is smaller than the quark model predictions but it is well reproduced by the recent QCD sum rule [91] and lattice [89] calculations.

The situation with Γ_L/Γ_T is still controversial. The three measurements: $1.8^{+0.7}_{-0.5}$ (E691 [92]), $0.5^{+1.0}_{-0.2}$ (MARKIII [93]), and 1.2 ± 0.2 (E653 [87]), agree within errors but differ considerably in their central values. The E691 value is close to the result of the QCD lattice calculations (1.7 ± 0.6) [89], while the QCD sum rule approach [91] prefers a value (0.86 ± 0.06) close to MARKIII and E653 results.

Recently E691 [92] and E653 [87] have managed to extract from their data all three form factors describing this decay. The results are shown in table 17 [87]. Again QCD sum rule and lattice calculations describe data better than quark models. In particular, the QCD lattice calculations [89] predicted the smallness of the a_+ form factor (in notations of reference [87]).

The D meson inclusive semileptonic width ($(18.1 \pm 1.3) \times 10^{10} sec^{-1}$ [22]) is about 30% larger than the sum of the widths for semileptonic D decays into K, K^*, and π ($(12.6\pm1.0) \times 10^{10} sec^{-1}$ [87]). However, there is no convincing evidence for multiparticle final states [87].

ARGUS [94] and CLEO [95] have studied semileptonic Λ_c^+ decays. For the decay $\Lambda_c^+ \to \Lambda X l\nu$ they obtained branching ratios of $(1.57 \pm 0.4 \pm 0.5)\%$ and $(3.1 \pm 0.9)\%$, respectively. The CLEO number is larger but they do not subtract background from Ξ_c semileptonic decays. The branching ratios are calculated taking $BR(\Lambda_c^+ \to$

Table 15: Branching ratios for D_s^+ decays relative to $BR(D_s^+ \to \phi\pi^+)$.
a) ARGUS [79,82], c) CLEO [81,84], e) E691 [83], p) PDG [22].

Mode	Experiment	Theory	
		BS[85]	BSW[23]
$\overline{K^0}K^+$	$0.97 \pm 0.17^{p)}$	0.43	0.48
$\overline{K^{*0}}K^+$	$0.96 \pm 0.11^{p)}$	0.73	0.86
$\overline{K^0}K^{*+}$	$1.2 \pm 0.21 \pm 0.07^{p)}$	0.05	0.11
$(K^+K^-\pi^+)_{nr}$	$0.25 \pm 0.07 \pm 0.05^{p)}$		
$f_0(975)\pi^+$	$0.28 \pm 0.10 \pm 0.03^{p)}$		
$\pi^+\pi^+\pi^-$	$0.44 \pm 0.10 \pm 0.04^{p)}$		
$(\pi^+\pi^+\pi^-)_{nr}$	$0.29 \pm 0.09 \pm 0.03^{p)}$		
$\phi\pi^+\pi^+\pi^-$	$0.48 \pm 0.20^{p)}$		
$\phi\pi^+\pi^0$	$2.4 \pm 1.0 \pm 0.5^{p)}$		
$\phi\rho^+$	$1.86 \pm 0.26 \pm 0.19^{c)}$		6.3
$\eta\rho^+$	$2.93 \pm 0.45 \pm 0.29^{c)}$	2.2	2.0
$\eta'\rho^+$	$3.55 \pm 0.71 \pm 0.36^{c)}$		0.55
$\eta\pi^+$	$0.54 \pm 0.09 \pm 0.05^{c)}$	1.2	1.0
$\eta'\pi^+$	$1.22 \pm 0.16 \pm 0.12^{c)}$	0.10	0.61
$\overline{K^{*0}}K^{*+}$	$1.6 \pm 0.4 \pm 0.4^{a)}$		1.2
$\phi l\nu$	$< 0.45^{e)}$ $0.49 \pm 0.1^{+0.10e)}_{-0.14}$ $0.57 \pm 0.15 \pm 0.15^{a)}$		

Table 16: Decay width for semileptonic D meson decays ($10^{10} sec^{-1}$).

Mode	Experiment [87]	Quark model [88]	QCD sum rules [91]	QCD lattice calculations [89]
$Kl\nu$	7.0 ± 0.7	8.3	6.4 ± 3	4.9 ± 0.7
$K^*l\nu$	4.7 ± 0.6	9.5	3.8 ± 1.5	5.2 ± 2.0

Table 17: Form factors for the decay $D \to \overline{K^*}l\nu$

Group	$a_+(0)/f(0)$	$g(0)/f(0)$
E691 [92]	0.00 ± 0.06	0.26 ± 0.08
E653 [87]	-0.09 ± 0.03	0.26 ± 0.04
Theory		
LMS [89]	-0.01 ± 0.09	0.21 ± 0.03
BBD [91]	-0.16 ± 0.03	0.29 ± 0.03
BSW [23]	-0.17	0.14

Table 18: Ratio $R = \frac{\Gamma(D \to \overline{K^*}l\nu)}{\Gamma(D \to \overline{K}l\nu)}$

Experiment	R
E691	$0.45 \pm 0.09 \pm 0.07$
MARK III	$1.0^{+0.3}_{-0.2}$
CLEO	$0.51 \pm .18 \pm 0.06$
ARGUS	$0.51 \pm 0.18 \pm 0.06$

$pK^-\pi^+) = (4.1 \pm 1.1)\%$ [99,100]. One expects that the decay $\Lambda_c^+ \to \Lambda X l\nu$ is dominated by the $\Lambda l\nu$ final state [97,96] for which theory predicts values from 1.4% to 5.7% [98,96].

Semileptonic charm decays provide excellent testing ground for different theoretical approaches. QCD sum rule and lattice calculations agree with

the experimental data within errors which are dominated by theoretical uncertainties. This provides a hope for an accurate model independent description of these decays in future. Within the HQET framework it is possible to relate semileptonic D and B decays. Therefore one can use measured decays of D mesons in order to make predictions for B meson decays. For example $\Gamma(B^0 \to \pi^- l^+ \nu) = |V_{ub}|^2 (1.71 \pm 0.12) \times 10^{-11} GeV$ is predicted [101] using measurements of $D^0 \to K^- l^+ \nu$. Such relations give additional motivation for studies of semileptonic charm decays.

TAU LEPTON DECAYS.

The discussion of τ lepton is limited to recent studies of τ decays. Tau lifetime measurements and τ pair production in Z^0 decays are discussed at this Conference by P.Roudeau [3] and J.Carter [102], respectively.

More then 20 new precise measurements of τ decays have been presented this year, mainly by the LEP experiments, ARGUS, and CLEO.

LEP provides very clean conditions for studying τ leptons. Multihadron events have higher multiplicity at LEP than at lower energies and two photon reactions are relatively unimportant due to the presence of the Z^0 resonance. For example ALEPH has a $q\bar{q}$ contamination in their $\tau^+\tau^-$ sample of only $(0.24 \pm 0.06)\%$ [103]. Decay products of a τ lepton are collimated in a very small cone due to a large Lorentz boost and have large energies. Therefore a high efficiency for τ events has been achieved by all four LEP experiments [104] with a highest value of $(72.40 \pm 0.24)\%$ obtained by ALEPH [103]. A high detection efficiency compensates partially a small production rate of τ leptons at Z^0 : $BR(Z^0 \to \tau^+\tau^-) = 3.33 \pm 0.13\%$ [22]

These advantages allowed LEP experiments to reach world average accuracy in topological branching ratios which are listed in table 19 together with recent ARGUS measurements [107]. The systematic uncertainties in LEP measurements are smaller than statistical errors. Therefore we can anticipate even higher precision in the nearest future.

1. Leptonic Decays of τ Lepton

Recent measurements of leptonic branching ratios of the τ lepton are summarized in table 20. There is good agreement between different experiments. The e/μ universality predicts

$$\frac{BR(\tau^- \to \mu^- \nu_\tau \overline{\nu_\mu})}{BR(\tau^- \to e^- \nu_\tau \overline{\nu_e})} = 0.973$$

because of larger μ mass. The experimental value of 0.982 ± 0.019 agrees within errors with this prediction. Assuming the e/μ universality one can improve the accuracy in electronic branching ratio by using measurements of $\tau^- \to \mu^- \nu_\tau \overline{\nu_\mu}$ as well. This leads to

$$BR(\tau^- \to e^- \nu_\tau \overline{\nu_e}) = 17.80 \pm 0.17\%$$

In the SM the electronic branching ratio can be accurately calculated :

$$BR(\tau^- \to e^- \nu_\tau \overline{\nu_e}) = \frac{\tau_\tau}{\tau_\mu} \left(\frac{G_F^\tau}{G_F^\mu}\right)^2 \left(\frac{m_\tau}{m_\mu}\right)^5 .$$

Recent measurements of τ lifetime by all four LEP experiments and by CLEO averaged with the PDG value give [3] $\tau_\tau = (302.5 \pm 5.9)\ fs$. Using this value for τ lifetime and assuming $G_F^\tau = G_F^\mu$,one gets a prediction

$$BR(\tau^- \to e^- \nu_\tau \overline{\nu_e}) = (18.84 \pm 0.41)\%,$$

which is 2.3 standard deviations higher than the direct measurement. The statistical significance of the discrepancy is small and moreover the formal averaging of errors in different measurements of branching ratios and τ lifetime can underestimate some common systematic effects. However, the discrepancy questions the fundamental assumptions of the theory and therefore attracts large attention and triggers speculations about possible new physics beyond the SM. It is interesting to notice that the CLEO measurement of

$$BR(\tau^- \to e^- \nu_\tau \overline{\nu_e}) = (19.0 \pm 0.4 \pm 0.7)\%$$

agrees nicely with the value predicted from lifetime measurements. On the other hand the ALEPH measurement of the τ lifetime ($(276 \pm 16)\ fs$) corresponds to τ lepton branching ratio smaller than the world average.

Table 19: Topological τ branching ratios in [%]

Experiment	B_1	B_3	B_5
ALEPH [104]	$85.56^{+0.40}_{-0.37} \pm 0.12$	$14.24^{+0.39}_{-0.40} \pm 0.13$	$0.10^{+0.05}_{-0.04} \pm 0.03$
L3 [104]	$85.6 \pm 0.6 \pm 0.3$	$14.4 \pm 0.6 \pm 0.3$	< 0.34 95% CL
OPAL [104]	$85.39^{\pm}0.46^{+0.47}_{-0.37}$	$14.50 \pm 0.46^{+0.53}_{-0.47}$	$0.11 \pm 0.08^{+0.14}_{-0.11}$
ARGUS [107]	–	$13.3 \pm 0.3 \pm 0.6$	–
PDG [22]	86.13 ± 0.33	13.76 ± 0.32	0.113 ± 0.027
Average	85.81 ± 0.22	13.97 ± 0.21	0.111 ± 0.024

Table 20: Leptonic branching ratios of τ lepton in [%].

Experiment	$\tau^- \to e^- \nu_\tau \overline{\nu_e}$	$\tau^- \to \mu^- \nu_\tau \overline{\nu_\mu}$
ALEPH [103]	$18.02 \pm 0.44 \pm 0.38$	$17.28 \pm 0.41 \pm 0.32$
OPAL [105]	$17.4 \pm 0.5 \pm 0.4$	$16.8 \pm 0.5 \pm 0.4$
L3 [106]	$17.5 \pm 0.8 \pm 0.5$	$17.7 \pm 0.7 \pm 0.6$
CLEO [114]	$19.0 \pm 0.4 \pm 0.7$	–
ARGUS [107]	$17.3 \pm 0.4 \pm 0.5$	$17.2 \pm 0.4 \pm 0.5$
CELLO [111]	$18.4 \pm 0.8 \pm 0.4$	$17.7 \pm 0.8 \pm 0.4$
PDG [22]	17.7 ± 0.4	17.8 ± 0.4
Average	17.73 ± 0.23	17.41 ± 0.24

The ratio of the hadronic and leptonic width of the τ lepton

$$R_\tau = \frac{\Gamma(\tau^- \to \nu_\tau + hadrons)}{\Gamma(\tau^- \to e^- \nu_\tau \overline{\nu_e})}$$

can be calculated using QCD [108]. Taking $\alpha_s(M_Z) = 0.120 \pm 0.007$ from LEP measurements one gets [108]

$$R_\tau^{Th} = 3.68^{+0.42}_{-0.21}.$$

This value is closer to the experimental value obtained from the measurement of $BR(\tau^- \to e^- \nu_\tau \overline{\nu_e})$ ($R_\tau = 3.63 \pm 0.04$) than to the value infered from the τ lepton lifetime ($R_\tau = 3.32 \pm 0.08$), but errors are too large to discriminate between them.

2. Hadronic Decay Modes of τ Lepton.

There is the second long-standing controversy with the τ lepton - the so called "one-prong problem" [109] .

The sum of measured exclusive branching ratios is smaller than 100% if one takes the formal world average values for them (see table 21, where h^- stands for π^- or K^-). Measurements of topological branching ratios show that the "missing" decay modes lead mainly to one-prong final states. The calculation of world averages and especially their errors is not a trivial procedure [110] (in fact several old results have not been used in calculations for table 21 because of problems with normalization and interpretation).

It is easier to compare results of individual experiments. ALEPH and ARGUS represent good examples. They have measured almost all major τ decays using different techniques (see table 21). ARGUS measures individual branching ratios while ALEPH uses the so called global method pioneered by CELLO [111]. In this method one first selects a clean sample of $\tau^+\tau^-$ events and than distributes them among the known (generic) final states. Contrary to a common belief this procedure does not automatically

Table 21: Branching ratio for major τ lepton decays (see text).

τ^- decay mode	Theory [%]	World average [%]	ARGUS [%]	ALEPH [%]
$e^-\nu_\tau\overline{\nu_e}$	17.8	17.73 ± 0.23	17.3 ± 0.6	18.0 ± 0.6
$\mu^-\nu_\tau\overline{\nu_\mu}$	17.3	17.41 ± 0.24	17.2 ± 0.6	17.3 ± 0.5
$(\pi^- + K^-)\nu_\tau$	11.4	12.33 ± 0.33	11.7 ± 1.0	12.5 ± 0.5
$\rho^-\nu_\tau$	23.5	23.01 ± 0.55	22.3 ± 1.0	24.5 ± 1.0
$K^{*-}\nu_\tau$	1.14	1.45 ± 0.13	1.2 ± 0.3	(1.45)
$"h^-h^-h^+"\nu_\tau$	(11.7)	7.80 ± 0.29	7.4 ± 0.5	9.5 ± 0.7
$"h^-\pi^0\pi^0"\nu_\tau$	(11.7)	8.27 ± 0.47	(7.4 ± 0.5)	10.2 ± 1.0
$"h^-h^-h^+\pi^0"\nu_\tau$	4.3	5.26 ± 0.32	5.4 ± 0.6	4.9 ± 0.7
$"h^-\pi^0\pi^0\pi^0"\nu_\tau$	1.08	0.86 ± 0.21	(1.08)	1.4 ± 0.6
Σ	100	94.12 ± 1.00	$91.0 \pm 1.4 \pm 3.0$	99.8 ± 1.6

lead to a sum of 100% for the considered branching ratios. Efficiencies for hypothetical new decays can differ from the efficiencies calculated in this method on the basis of standard decays. In the global method one fits all branching ratios simultaneously taking into account migration of each decay as a background into different channels. It is superior to a classical approach of measuring individual channels, provided the migration matrix is exactly known and the τ sample is very clean. In this respect ALEPH is in much better position than CELLO. ALEPH has more than factor of two smaller background and larger efficiency. By normalizing to the number of hadronic Z^0 decays, they know accurately the number of produced $\tau^+\tau^-$ pairs (8620 ± 50) [103]. And finally, their migration matrix is much more diagonal. For example, about 13% of $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ decays are reconstructed as $\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$ decays and this in one of the largest migration probabilities in the ALEPH analysis.

ARGUS has not measured channels with two or more π^0. Since isospin conservation requires $BR(\tau^- \to \pi^-\pi^0\pi^0\nu_\tau) \leq BR(\tau^- \to \pi^-\pi^+\pi^-\nu_\tau)$ the measurement of the later channel is used in table 21 as an upper bound for $BR(\tau^- \to \pi^-\pi^0\pi^0\nu_\tau)$. The theoretical prediction based on CVC and hadron production in e^+e^- annihilation is used for $BR(\tau^- \to \pi^-\pi^0\pi^0\pi^0\nu_\tau)$. In case of ALEPH the world average for $BR(\tau^- \to K^{*-}\nu_\tau)$ is added to channels measured in this experiment.

The sum of branching ratios in the ARGUS analysis is considerably smaller than 100%. However, the systematic errors are large and the deviation from 100% does not reach a 3σ level. The sum of ALEPH measurements is close to 100% with a very small error.

Both experiments agree with theoretical predictions normalized to the measured electronic branching ratio. However, in the three pion channels reliable theoretical estimates do not exist. In the table 21 the theoretical predictions for these two channels are substituted by equal values (suggested by a_1^- dominance in $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ decay) which add up the sum of branching ratios to 100%. And just this three pion channel is the main source of difference between the ALEPH and ARGUS measurements.

Both experiments are comparable in their ability to measure $BR(\tau^- \to \pi^-\pi^+\pi^-\nu_\tau)$. ARGUS has a considerably larger hadronic background in this channel of about 7% [112] . However, this background can be reliably estimated and moreover can be reduced to a less than 1% level by requiring a leptonic decay of the second τ lepton [113]. ARGUS has a 2.5 times smaller efficiency of about 20% but about 14 times larger number of detected events. The most important background due to migration of events from the $\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$ channel is comparable in both experiments. Thus there is no obvious advantage of one experiment over the other. And in fact the difference between their results on $BR(\tau^- \to \pi^-\pi^+\pi^-\nu_\tau)$ does not reach a 3σ level.

At this Conference CLEO presented the most precise measurements of the decays [114] $\tau^- \to h^-\pi^0\pi^0\nu_\tau$ and $\tau^- \to h^-\pi^0\pi^0\pi^0\nu_\tau$. Ex-

ploiting fine segmentation and high energy resolution of the CsI calorimeter , they reconstruct explicitly π^0 decays. The explicit reconstruction of π^0 reduced the cross talk to the $\pi^-\pi^0\pi^0\nu_\tau$ final state from other τ decays (mainly from $\tau \to \rho^-\nu_\tau$ channel) to about 9% level which should be compared with about 46% cross talk in case of the ALEPH analysis [103]. The reconstruction of the π^0 mesons allows CLEO to estimate a background using sidebands in the $\gamma\gamma$ invariant mass distributions without relying on the Monte Carlo simulation (which in fact does not describe their data well). The price for these advantages in the CLEO analysis is almost four times smaller efficiency.

Normalizing their results to the branching ratio $BR(\tau \to h^-\pi^0\nu_\tau)$ CLEO finds:

$$\frac{BR(\tau^- \to h^-\pi^0\pi^0\nu_\tau)}{BR(\tau^- \to h^-\pi^0\nu_\tau)} = 0.353 \pm 0.018 \pm 0.028,$$

$$\frac{BR(\tau^- \to h^-\pi^0\pi^0\pi^0\nu_\tau)}{BR(\tau^- \to h^-\pi^0\nu_\tau)} = 0.031 \pm 0.006 \pm 0.008.$$

Using PDG values [22] for

$$\begin{aligned} BR(\tau^- \to h^-\pi^0\nu_\tau) &= BR(\tau^- \to \rho^-\nu_\tau) + \\ BR(\tau^- \to K^{*-}\nu_\tau) &\times BR(K^{*-} \to K^-\pi^0) = \\ &= 0.232 \pm 0.008 \end{aligned}$$

CLEO obtains

$$BR(\tau^- \to h^-2\pi^0) = 8.19 \pm 0.42 \pm 0.65 \pm 0.28\%,$$

$$BR(\tau^- \to h^-3\pi^0) = 0.72 \pm 0.14 \pm 0.19 \pm 0.02\%,$$

where the first error is statistical , the second systematic and the third is due to normalization uncertainty. These values have been used for calculation of world averages in table 21. The CLEO result for $BR(\tau^- \to h^-\pi^0\pi^0)$ is smaller than the ALEPH value.However, if one uses for normalization the ALEPH value for $BR(\tau^- \to h^-\pi^0)$ the CLEO result will be closer to

$$BR(\tau^- \to h^-\pi^0\pi^0) = (10.21 \pm 0.66 \pm 0.80)\%$$

measured by ALEPH. Therefore we should wait for the absolute normalization of the CLEO result before making final conclusions.

To summarize, we can say that the "one-prong problem" has never been very statistically significant. New measurements show that the disagreement between different experiments is mainly due to τ decays into three pions. Using the global method CELLO [111] and ALEPH [103] find a sum of measured τ branching ratios close to 100%. This makes the "one-prong problem" even more controversial.

Table 22: ARGUS upper limits on neutrinoless τ decays at 90%CL.

decay channel	Upper Limit (10^{-5})
$\tau^- \to e^-e^+e^-$	1.3
$\tau^- \to e^-\mu^+\mu^-$	1.9
$\tau^- \to e^+\mu^-\mu^-$	1.8
$\tau^- \to \mu^-e^+e^-$	1.4
$\tau^- \to \mu^+e^-e^-$	1.4
$\tau^- \to \mu^-\mu^+\mu^-$	1.9
$\tau^- \to e^-\pi^+\pi^-$	2.7
$\tau^- \to e^+\pi^-\pi^-$	1.8
$\tau^- \to \mu^-\pi^+\pi^-$	3.6
$\tau^- \to \mu^+\pi^-\pi^-$	5.3
$\tau^- \to e^-\rho^0$	1.9
$\tau^- \to \mu^-\rho^0$	2.9
$\tau^- \to e^-\pi^+K^-$	2.9
$\tau^- \to e^+\pi^-K^-$	2.0
$\tau^- \to \mu^-\pi^+K^-$	11
$\tau^- \to \mu^+\pi^-K^-$	5.8
$\tau^- \to e^-K^{*0}$	3.8
$\tau^- \to \mu^-K^{*0}$	4.5
$\tau^- \to e^-\gamma$	12
$\tau^- \to e^-\pi^0$	17
$\tau^- \to \mu^-\gamma$	3.4
$\tau^- \to \mu^-\pi^0$	4.4
$\tau^- \to e^-\eta$	6.3
$\tau^- \to \mu^-\eta$	7.3
$\tau^- \to \bar{p}\,\gamma$	29.0
$\tau^- \to \bar{p}\,\pi^0$	65.5
$\tau^- \to \pi^-\gamma$	28
$\tau^- \to \pi^-\pi^0$	37
$\tau^- \to \bar{p}\,\eta$	129

ARGUS improved recently [112] upper limits on the neutrinoless τ decays. They are listed in table 22 and most of them are the world best limits.

3. Lorentz Structure of τ Decays

All available information on τ decays is consistent with standard $V-A$ coupling at the $\tau-\nu_\tau-W$ vertex.

The world average of the Michel parameter [115], $\rho = 0.727 \pm 0.033$, is in good agreement with the value of $\rho = 0.75$, expected for $V-A$ structure and excludes $V+A$, V , and A couplings.

The measurement of ν_τ helicity , performed for the first time by ARGUS [116] , depends sensitively on the D to S wave ratio in the decay $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ [117] . Using their high statistic sample of τ decays ARGUS determined this ratio to be $D/S = -0.11 \pm 0.02$ [112]. With measured D/S ratio and increased statistics ARGUS improves the accuracy in the ratio of axial and vector coupling of the τ lepton:

$$\gamma_{AV} = \frac{2\gamma_A\gamma_V}{\gamma_A^2+\gamma_V^2} = 1.25 \pm 0.23^{+0.15}_{-0.08} .$$

This value is in good agreement with the SM prediction of $\gamma_{AV} = +1$.

The ARGUS collaboration has measured ρ meson polarisation in the decay $\tau^- \to \rho^-\nu_\tau$. The helicity angular distribution of the π^- meson with respect to the ρ^- direction should exhibit $1 + b \cdot cos^2\theta_\pi$ behavior, with $b = 0.57$ at the Υ energy region. The helicity angular distribution measured by ARGUS [112] is shown in figure 23. It agrees nicely with the expectation. For the b parameter fit gives a value of $b = 0.57 \pm 0.12$.

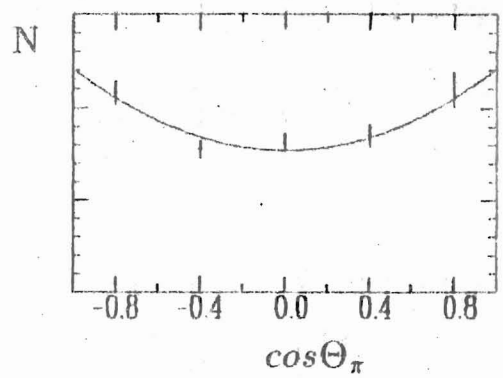

Figure 23: Helicity angle distribution for ρ^- decays.

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References

[1] K.Sliwa, *Talk at the 4th Int. Symp. on Heavy Flavour Physics*, Orsay (1991).

[2] For a recent review see ,e.g., K.Berkelman and S.Stone, *Preprint CLNS* 91-1044(1991); A.Golutvin, *Talk at the 4th Int. Symp. on Heavy Flavour Physics* , Orsay (1991); A.Ali, *Preprint DESY* 91-137 (1991); R.Kass, *Talk at the 4th Int. Symp. on Heavy Flavour Physics* , Orsay (1991); C.Kiesling, *Preprint DESY* 91-067 (1991).

[3] P.Roudeau, *Plenary talk at this Conference.*

[4] J.Alexander et al. (CLEO), *Phys.Rev.Lett.* **64** (1990) 2226.

[5] M.Danilov, *Proc. of the XXVth Rencontre de Moriond*, (1990) 349.

[6] R.Fulton et al. (CLEO), *Phys.Lett.* **B224** (1989) 445.

[7] A.Yu.Khodjamirian, S.Rudaz and M.Voloshin, *Phys.Lett.* **B242** (1990) 489.

[8] D.Atwood, A.Soni and D.Wyler, *Phys.Rev.Lett.* **65** (1990) 2335.

[9] D.Atwood et al., *Preprint* BNL-46242 (1991); E.Ma,*Preprint* UCRHEP-T75 (1991); E.Ma,*Preprint* UCRHEP-T81 (1991), *Phys.Rev.Lett.* **65** (1990) 2335.

[10] A.I.Vainshtein and L.B.Okun, *Sov.J.Nucl.Phys.* **23**, 716 (1976); L.B.Okun and M.B.Voloshin, *JETP Lett.* **23**, 369 (1976); A.De Rujula, H.Georgi and S.Glashow, *Phys.Rev.Lett.* **38**, 317 (1977); H.S.Lipkin,*Phys.Lett.* **B179**(1986)278; S.Ono, A.I.Sanda and N.A.Tornquist, *Phys. Rev.* **D34** (1986) 186.

[11] J.Lee-Franzini, *Talk at the Moriond XXVI Conference*, 1991.

[12] K.Berkelman and S.Stone, *Preprint CLNS* 91/1089, 1991.

[13] Y.Kubota et al. (CLEO), *Paper submitted to this Conference.*

[14] H.Fritzsch and J.H.Kühn, *Phys. Lett.* **B90** (1980) 164; J.H.Kühn and H.Schneider, *Z.Phys.* **C11** (1981) 263.

[15] H.Albrecht et al. (ARGUS), *Z.Phys.* **C48** (1990) 543.

[16] H.Albrecht et al. (ARGUS) *Preprint DESY* 91-121 (1991).

[17] D.Bortoletto et al. (CLEO) *Preprint CLNS* 91/1102 (1991).

[18] D.Atwood and W.J.Marciano, *Phys.Rev.* **D41** (1990) 1736.

[19] G.P.Lepage, *Phys.Rev.* **D42** (1990) 3251.

[20] N.Byers and E.Eichten, *Phys.Rev.* **D42** (1990) 3885.

[21] J.Adler et al. (MARKIII) *Phys.Rev.Lett.* **60** (1988) 89; J.Adler et al. (MARKIII) *Phys.Lett.* **B208** (1988) 152.

[22] Particle Data Group, *Phys.Lett.* **B239** (1990) 1,

[23] M.Bauer, B.Stech and M.Wirbel, *Z.Phys.* **C34** (1987) 103.

[24] D.Bortoletto et al. (CLEO) *Phys.Rev.Lett.* **64** (1990) 2117.

[25] J.Adler et al. (MARKIII) *Phys.Rev.Lett.* **60** (1988) 1375.

[26] E.Eichten and B.Hill, *Phys.Lett.* **B234** (1990) 511; H.Politzer and M.Wise, *Phys.Lett.* **B206** (1988) 681 and *Phys.Lett.* **B208** (1988) 504; N.Isgur and M.Wise, *Phys.Lett.* **B232** (1989) 113 and *Phys.Lett.* **B237** (1990) 527; B.Grinstein, *Nucl.Phys.* **B339** (1990) 253; H.Georgi, *Phys.Lett.* **B240** (1990) 447; J.D.Bjorken, *SLAC preprint*,SLAC-PUP-5278, 1990; A.Falk, H.Georgi, B.Grinstein and M.Wise, *Nucl.Phys.* **B343** (1990) 1; A.Falk and B.Grinstein,

Phys.Lett. **B247** (1990) 406;
T.Mannel, *Talk at this Conference;*
M.Neubert, *Talk at this Conference.*

[27] J.L.Rosner, *Phys.Rev,* **D42** (1990) 3732.

[28] D.Bortoletto and S.Stone,
Phys.Rev.Lett. **65** (1990) 2951.

[29] P.H.Cox, S.Hovater, and S.T.Jones,
Phys.Rev. **D32** (1985) 1157.

J.H.Kühn and R.Rückl,
Phys.Lett. **135B** (1984) 477.

N.G.Deshpande and J.Trampetic,
Phys.Rev. **D41** (1990) 986.

J.H.Kühn, S.Nussinov and R.Rückl,
Z.Phys. **C5** (1980) 117..

[30] See, e.g., *SLAC Workshop on B factory, Preprint* SLAC-373(1991).

[31] H.Schröder, *Int. Conf. on High Energy Physics,* Singapore, 1990.

[32] Reported by I.Bigi at the *Workshop on KEK B factory* , Tsukuba, 1991.

[33] For a recent review see, e.g.,
L.Maiani, *Rome preprint* n.798,(1991).

[34] For a review see, e.g. W.-S.Hou,*XXIV Int. Conf. on High Energy Phisics* , Munich (1988).

[35] S.Henderson et al.(CLEO),
Preprint CLNS 91/1101, 1991.

[36] G.Altarelli and S.Petrarka,
Phys.Lett. **B263** (1991) 325.

[37] G.Altarelli, N.Cabibbo, G.Corbo,
L.Maiani and G.Martinelli,
Nucl.Phys. **B208** (1982) 365.

[38] H.Albrecht et al.(ARGUS),
Phys.Lett. **B249** (1990) 359.

[39] N.Isgur et al., *Phys.Rev.* **D39** (1989) 799.

[40] A.Dobrovolskaya, *Talk at the 4th Int. Symp. on Heavy Flavour Physics* , Orsay (1991).

[41] H.Albrecht et al. (ARGUS),
Phys.Lett. **B197** (1987) 452 and **B219** (1989) 121.

[42] D.Antreasyan et al. (Crystal Ball),
Z.Phys. **C48** (1990) 553.

[43] D.Bortoletto et al. (CLEO),
Phys.Rev.Lett. **63**(1989) 1667.

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

[45] J.S.Korner and G.A.Shuler,
Z.Phys. **C38** (1988) 511.

[46] J.M.Cline, W.F.Palmer and G.Kramer,
Phys.Rev. **D40** (1989) 793.

[47] M.Voloshin and M.Shifman,
Sov.J.Nucl.Phys. **45** (1987) 292 and
Sov.J Nucl.Phys. **47** (1988) 511.

[48] M.Neubert, *Phys. Lett.* **B264** (1991) 455.

[49] H.Albrecht et al. (ARGUS),
Preprint DESY 91-122(1991).

[50] H.Albtercht et al. (ARGUS),
Phys. Lett. **229** (1989) 175.

[51] R.Fulton et al. (CLEO),
Phys.Rev. **D34**(1991) 651.

[52] B.Redy,*Private communication.*

[53] H.Albrecht et al.(ARGUS),
Phys.Lett. **B234** (1990) 409.

[54] R.Fulton et al.(CLEO),
Phys.Rev.Lett. **64** (1990) 16.

[55] H.Albrecht et al.(ARGUS),
Phys.Lett. **B255** (1991) 297.

[56] See for example, G.Kramer and W.F.Palmer, *Phys.Rev.* **D42** (1990) 85 and references therein.

[57] M.Paulini, *Talk at this Conference.*

[58] H.Albrecht et al.(ARGUS),
Phys.Lett. **B192** (1987) 245.

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

[60] H.Albrecht et al.(ARGUS), to be published.

[61] M.B.Voloshin, M.A.Shifman,*Sov.Phys. JEPT* **64** (1986) 698.

[62] M.Battle et al. (CLEO), *Paper submitted to this Conference.*

[63] T.Lesiak et al. (Crystal Ball) *Preprint DESY 91-075.*

[64] H.Albrecht et al.(ARGUS), *Phys.Lett.* **B229** (1988) 304.

[65] See references in [64]. For more recent results see A.Ali, T.Mannel, *Phys.Lett.* **B264** (1991) 447. and references therein.

[66] G.Cella et al., *Phys.Lett.* **B248** (1990) 181.

[67] M.Schmidtler and K.R.Schubert, *Karlsruhe Preprint* IEKP-KA/91-4 (1991).

[68] L.Wolfenstein, *Phys.Rev.Lett.* **51** (1983) 1945.

[69] C.Baglin et al.(R708), *Phys.Lett.* **B171** (1986) 135.

[70] S.Palestini, *Talk at this Conference.*

[71] A.Martin, *Talk at this Conference.*

[72] For a review see, e.g., J.L.Rosner, *Preprint EFI* 90-63 (1990).

[73] V.L.Eletsky and Ya.I.Kogan, *Z.Phys.* **C28** (1985) 155.

[74] M.Goldberg et al. (CLEO), *Paper submitted to this Conference.*

[75] R.Ammar et al. (CLEO), *Paper submitted to this Conference.*

[76] For a review see,e.g., M.S.Shifman,*Proceedings of the 1987 Int. Symp. on Lepton and Photon Interactions at High Energies,* Hamburg, (1987) P.E.Karshin,*Proceedings of the 1989 Int. Symp. on Lepton and Photon Interactions at High Energies,* Stanford, (1989)

[77] R.Ammar et al. (CLEO), *Preprint CLNS* 91/1058 (1991).

[78] J.C.Anjos et al. (E691) *Phys.Rev.* **D43** (1991) 635.

[79] H.Albrecht et al. (ARGUS), *Preprint DESY* 91-066 (1991).

[80] G.Wormser et al. (MARK II), *Phys.Rev.Lett.* **61**, (1988) 1057.

[81] R.J.Morrison et al. (CLEO), *Paper submitted to this Conference.*

[82] H.Albrecht et al. (ARGUS), *Phys.Rev.* **B255** (1991) 634.

[83] J.C.Anjos et al. (E691) *Phys.Rev.Lett.* **64** (1990) 2885.

[84] J.Alexander et al. (CLEO) *Phys.Rev.Lett.* **65** (1990) 1531.

[85] Yu.Block, M.A.Shifman, *Yad.Fiz.* **45** (1987) 211,478,841.

[86] J.C.Anjos et al. (E691), *Phys.Rev.Lett.* **62**, (1989) 722.

[87] D.M.Potter,*Talk at this Conference.*

[88] M.Wirbel,B.Stech,M.Bauer, *Z.Phys.* **C34** (1987) 103, M.Bauer and M.Wirbel, *Z.Phys.* **C42** (1989) 671.

[89] V.Lubicz,G.Martinelli and C.T.Sachrayda, *Nucl.Phys.* **B356** (1991) 301.

[90] G.Crawford et al. (CLEO), *Preprint CLNS* 91/1083 (1991).

[91] P.Ball,V.M.Braun and H.G.Dosch, *Preprint* HD-THEP-91-16 (1991).

[92] J.C.Anjos et al. (E691), *Phys.Rev.Lett.* **65**, (1990) 2630.

[93] Z.Bai et al. (MARK III), *Phys.Rev.Lett.* **66**, (1991) 1011. J.Adler et al. (MARKIII) *Phys.Rev.Lett.* **62**, (1989) 1821.

[94] H.Albrecht et al. (ARGUS), *Preprint DESY* 91-055 (1991).

[95] D.Bortoletto et al. (CLEO), *Paper submitted to this Conference.*

[96] R.Perez-Marcial et al., *Phys.Rev.* **D40**, (1989) 2955.

[97] S.R.Klein et al., *Phys.Rev.Lett.* **62**, (1989) 2444.

[98] J.G.Körner and H.W.Siebert, *Preprint* MZ-TH/91-08 (1991)

[99] H.Albrecht et al. (ARGUS), *Phys.Lett.* **B210**, (1988) 263.

[100] P.Avery et al. (CLEO), *Preprint CLNS* 90-922 (1990).

[101] G.Kramer, T.Mannel, and G.Schuler, *Z.Phys.* **C51** (1991) 649.

[102] J.Carter, *Plenary Talk at this Conference.*

[103] M.Davier, *Private communication;* A.-M.Lutz, *Talk at the 4th Int. Symp. on Heavy Flavour Physics* , Orsay (1991).

[104] S.Komamiya, *Talk at this Conference.*

[105] G.Alexander et al.(OPAL), *Preprint* CERN-PFE/91-103

[106] L3 Collaboration, *Phys.Lett.* **B265** (1991) 451.

[107] H.Albrecht et al. (ARGUS), *Preprint DESY* 91-084 (1991).

[108] For a review see S.Narison, *Talk at this Conference.*

[109] F.J.Gilman and S.H.Rhie, *Phys.Rev.* **D31** (1985) 1066; T.N.Truong, *Phys.Rev.* **D30** (1984) 1509.

[110] K.G.Hyes and M.L.Perl, *Phys.Rev.* **D38** (1988) 3351.

[111] H.J.Berend et al. (CELLO) *Z.Phys.* **C46** (1990) 537.

[112] D.Wegener, *Talk at this Conference.*

[113] H.Albrecht et al. (ARGUS), *Phys.Lett.* **B246**, (1990) 278.

[114] R.Stroynowski, *Talk at this Conference.*

[115] For a compilation see reference [113].

[116] H.Albrecht et al. (ARGUS), *Phys.Lett.* **B250**, (1990) 164.

[117] J.H.Kühn and F.Wagner *Nucl.Phys.* **B236** (1984) 16; M.Feindt, *Z.Phys.* **C48** (1990) 681.