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RECENT ARGUS AND CLEO RESULTS ON τ LEPTON AND CHARM

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RECENT ARGUS AND CLEO RESULTS ON τ-LEPTON AND CHARM: Preprint ITEP 94-53/

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Recent ARGUS and CLEO results on τ lepton and charm are reviewed. Many τ branching ratios have been precisely measured including $\mathcal{B}(\tau^- \to h^-\pi^0\nu_\tau) = (25.87 \pm 0.12 \pm 0.42)\%$. The Michel parameter η has been measured for the first time ($\eta = 0.03 \pm 0.18 \pm 0.12$) using the shape of muon spectrum in the decay $\tau \to \mu\nu\bar{\nu}$. Using spin correlations of $\tau^+\tau^-$ produced at $\sqrt{s} = 10\ GeV$ the parameter γ_{AV} has been measured to be $\gamma_{AV} = 1.021 \pm 0.028 \pm 0.030$. New excited charmed meson ($D^*_{SJ}(2573)^+$) and baryon ($\Lambda_c^{*+}(2530)$) have been observed. New Cabibbo suppressed D^0 decays have been measured and evidence for the doubly Cabibbo suppressed decay $D^0 \to K^+\pi^-$ has been obtained. Absolute branching ratios of D^0 and D^+ mesons have been determined using correlations with soft pions from D^{*+} decays.

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1 Tau lepton

1.1 Branching ratios of τ decays

For quite some time the sum of measured exclusive branching ratios of τlepton was smaller than 100% [1]. However in so-called global approach there was no deficit [2]. The major uncertainties were in the channels with π^0. Most accurate measurements of τ decays into one charged hadron and 2,3, and 4 π^0 were performed by CLEO [3].

In order to convert these ratios into branching ratios one needs $\mathcal{B}(\tau^- \to h^-\pi^0\nu)$. Recently CLEO performed a precision measurement of this channel [4]. They studied events in which both τ decayed into $h^\pm\pi^0\nu$ and events in which one τ decayed into $h^\pm\pi^0\nu$ while another one into $e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$, $h^\pm\pi^0\nu$, or $h^+h^-h^\pm(\pi^0)\nu$.

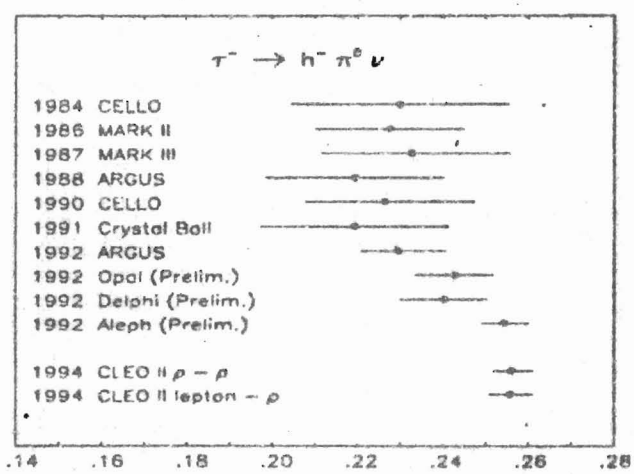

Figure 1: Branching ratio of the decay $\tau^- \to h^-\pi^0\nu_\tau$.

The combined result

$$\mathcal{B}(\tau^- \to h^-\pi^0\nu) = (25.87 \pm 0.12 \pm 0.42)\%$$

is in a good agreement with the ALEPH measurement [5] but somewhat higher than previous measurements by other groups (see Fig. 1). Using this result CLEO obtains branching ratios for multi π^0 final states

$$\mathcal{B}(\tau^- \to h^-\pi^0\pi^0\nu) = (8.84 \pm 0.15 \pm 0.44)\%,$$

$$\mathcal{B}(\tau^- \to h^-\pi^0\pi^0\pi^0\nu) = (1.05 \pm 0.08 \pm 0.12)\%.$$

$$\mathcal{B}(\tau^- \to h^-\pi^0\pi^0\pi^0\pi^0\nu) = (0.15 \pm 0.05 \pm 0.05)\%.$$

Table 1: Branching ratios of τ one-prong decays.

Mode	Expt	$\mathcal{B}(\%)$
$e^-\bar{\nu}_e\nu_\tau$	CLEO	17.97 ± 0.27
$\mu^-\bar{\nu}_\mu\nu_\tau$	WAvg	17.34 ± 0.16
$h^-\nu_\tau$	WAvg	12.56 ± 0.21
$h^-\pi^0\nu_\tau$	CLEO	25.61 ± 0.43
$h^-\pi^0\pi^0\nu_\tau$	CLEO	8.84 ± 0.46
$h^-\pi^0\pi^0\pi^0\nu_\tau$	CLEO	1.05 ± 0.15
$h^-\pi^0\pi^0\pi^0\pi^0\nu_\tau$	CLEO	0.15 ± 0.07
$h^-\bar{K}^0(\pi^0)\nu_\tau$	WAvg	0.92 ± 0.11
$(\bar{K}^0 \to K_L, \pi^0\pi^0)$		
$h^-\omega\nu_\tau; \omega \to \pi^0\gamma$	WAvg	0.14 ± 0.04
$h^-\eta\pi^0\nu$	CLEO	0.06 ± 0.01
$(\eta \to \gamma\gamma)$		
Total		84.64 ± 0.76
Topological 1-prong	WAvg	85.16 ± 0.19
discrepancy		0.52 ± 0.79

Table 1 summarizes branching ratios of τ one-prong decays with CLEO measurements shown when available. The sum of exclusive branching ratios practically coincides with the topological one-prong branching ratio. There is no indication of the one-prong deficit any more.

The analysis of the spectral function in the $\pi^-\pi^0\nu$ final state reveals presense of ρ' with mass of 1351 ± 17 MeV and width of 486 ± 58 MeV.

The search for neutrinoless τ decays performed by CLEO resulted in a considerable improvement of upper limits as can be seen in table 2.

CLEO has also improved accuracy in τ five-prong branching ratios and Cabibbo-suppressed τ decays [6]. These results are shown in tables 3 and 4 respectively.

Table 2: Upper limits for branching ratios at 90% @ CL in units of 10^{-6}.

Decay channel	Detection efficiency, %	Events passed	CLEO	PDG	ARGUS
$\tau^- \to e^- e^+ e^-$	20.4	0	3.3	27	13
$\tau^- \to \mu^- e^+ e^-$	19.6	0	3.4	27	14
$\tau^- \to \mu^+ e^- e^-$	19.9	0	3.4	16	14
$\tau^- \to e^- \mu^+ \mu^-$	18.8	0	3.6	27	19
$\tau^- \to e^+ \mu^- \mu^-$	19.4	0	3.5	16	18
$\tau^- \to \mu^- \mu^+ \mu^-$	15.9	0	4.3	17	19
$\tau^- \to e^- \pi^+ \pi^-$	15.5	0	4.4	42	27
$\tau^- \to e^- \pi^- K^+$	14.6	0	4.6	58	-
$\tau^- \to e^- \pi^+ K^-$	14.9	1	7.7	42	29
$\tau^- \to e^+ \pi^- \pi^-$	15.5	0	4.4	17	18
$\tau^- \to e^+ \pi^- K^-$	15.1	0	4.5	49	20
$\tau^- \to \mu^- \pi^+ \pi^-$	9.1	0	7.4	39	36
$\tau^- \to \mu^- \pi^- K^+$	7.4	1	15	77	-
$\tau^- \to \mu^- \pi^+ K^-$	7.8	0	8.7	77	110
$\tau^- \to \mu^+ \pi^- \pi^-$	9.8	0	6.9	39	63
$\tau^- \to \mu^+ \pi^- K^-$	7.7	2	20	40	58
$\tau^- \to e^- \rho^0$	16.2	0	4.2	39	19
$\tau^- \to e^- K^{*0}$	10.7	0	6.3	54	38
$\tau^- \to e^- \bar{K}^{*0}$	10.5	1	11	-	-
$\tau^- \to \mu^- \rho^0$	11.9	0	5.7	38	29
$\tau^- \to \mu^- K^{*0}$	7.2	0	9.4	59	45
$\tau^- \to \mu^- \bar{K}^{*0}$	7.8	0	8.7	-	-

Table 3: Branching ratios of five-prong τ decays (CLEO).

Decay mode	$\mathcal{B}$[%]
$\tau^- \to 3\pi^- 2\pi^+ \geq 0$ neutrals ν_τ	$0.097 \pm 0.005 \pm 0.011$
$\tau^- \to 3\pi^- 2\pi^+ \nu_\tau$	$0.077 \pm 0.005 \pm 0.009$
$\tau^- \to 3\pi^- 2\pi^+ \pi^0 \nu_\tau$	$0.019 \pm 0.004 \pm 0.004$
$3\pi^- 2\pi^+ 2\pi^0 \nu_\tau$	$<$ 0.011 % @ 90%CL

Table 4: Branching ratios of Cabibbo suppressed τ decays (CLEO)

Decay mode	$\mathcal{B}$[%]
$\tau^- \to K^- X \nu_\tau$	$1.60 \pm 0.12 \pm 0.19$
$\tau^- \to K^- \nu_\tau$	$0.66 \pm 0.07 \pm 0.09$
$\tau^- \to K^- \pi^0 \nu_\tau$	$0.51 \pm 0.10 \pm 0.07$
$\tau^- \to K^- \pi^0 \pi^0 \nu_\tau$	< 0.3 @ 90% CL

1.2 Lorentz structure of τ decays

In contrast with the situation in τ branching ratios where all major modes have already been measured, the study of Lorentz structure of τ decays is still in its initial stage. Neglecting radiative corrections and finite mass effects one can write the lepton momentum spectrum in the decay $\tau \to \ell \bar{\nu} \nu$ as:

$$\frac{d\Gamma_{\tau\to\ell\bar{\nu}\nu}}{d\Omega dx} \propto x^2 G_\ell G_\tau \left\{ 12(1-x) + \rho \cdot (\frac{32x}{3} - 8) + \eta \cdot \frac{m_\ell}{m_\tau} \cdot \frac{24(1-x)}{x} \right.$$
$$\left. - P_\tau \cdot \xi \cdot \cos\eta \cdot [4(1-x) + \delta \cdot (\frac{32x}{3} - 8)] \right\}. \quad (1)$$

where $x = 2 \cdot E_\ell / m_\tau$ is the scaled lepton energy, ϑ the angle between the τ spin and the lepton momentum, and P_τ the τ polarization.

The Michel Parameters ρ, η, ξ, and δ are combinations of the ten complex coupling constants of the most general four-fermion Hamiltonian describing leptonic τ decays. In the Standard Model, pure V − A interaction is expected with $\rho = 0.75$, $\eta = 0$, $\xi = 1$, and $\delta = 0.75$. Different values of Michel parameters would demonstrate existence of New Physics beyond the Standard Model.

The Michel parameter ρ has been measured by several experiments with the most accurate measurement coming from ARGUS [7] $\rho = 0.742 \pm 0.035 \pm 0.020$. ARGUS has observed for the first time parity violation in τ decays and determined ν_τ helicity [8] $h_{\nu_\tau} = -1.25 \pm 0.23^{+0.08}_{-0.15}$. The

module of the Michel parameter $|\xi_\tau|$ was also measured by ARGUS [9] $|\xi_\tau| = 0.90 \pm 0.13 \pm 0.08$ while its positive sign can be obtained from a combination of LEP and ARGUS measurements.

Recently ARGUS performed a precision measurement of

$$\gamma_{AV} = \frac{2Re g_A g_V^*}{|g_V|^2 + |g_A|^2}$$

where g_V and g_A are vector and axial vector decay constants of τ lepton. The contribution of scalar (g_S) and pseudoscalar (g_P) couplings in τ decays has also been investigated. A precise measurement of the absolute value of γ_{AV} becomes possible by exploiting spin correlations in $\tau^+\tau^-$ events where both τ leptons decay semi-hadronically.

The electroweak production of τ pairs in e^+e^- colliders leads to correlations between the spins of both τ leptons, which become observable in the angular correlations between the final state hadrons. For example in the case of a vanishing τ mass the τ leptons have always opposite helicities, resulting in strong correlations between the decay products of the τ leptons. Because of experimental advantages - a large branching ratio of about 25% and a high detection efficiency for the decay $\tau^- \to \pi^-\pi^0\nu_\tau$ - the following reaction was considered

$$e^+e^- \to \tau^+\tau^- \to \bar{\nu}_\tau\pi^+\pi^0\,\nu_\tau\pi^-\pi^0. \tag{2}$$

The parameter γ^2_{AV} is determined using a likelihood method which exploits the whole kinematical information of reaction (2). The squared matrix element entering the likelihood function has been derived in [10] and can be written as

$$\left|M(\vec{\alpha}|\gamma^2_{AV})\right| = C[A(\vec{\alpha}) + \gamma^2_{AV}\cdot B(\vec{\alpha})].$$

with a factor C independent on γ^2_{AV} and functions $A(\vec{\alpha})$ and $B(\vec{\alpha})$ where $\vec{\alpha}$ represents eleven measurable quantities (nine angles and two invariant masses). Some of these quantities are only determined up to a twofold- ambiguity, because they require the knowledge of the τ direction of flight, which cannot be measured directly with the ARGUS detector. The kinematical information of the observed hadronic decay products of the τ pairs constrains the τ direction up to two solutions [10]. The sum of the two resulting squared matrix elements for each event can directly be used for the likelihood analysis, because phase space and flux factors cancel since only likelihood ratios are considered:

$$L(\gamma^2_{AV}) = \prod_i \left|M_i^1(\vec{\alpha}|\gamma^2_{AV})\right|^2 + \left|M_i^2(\vec{\alpha}|\gamma^2_{AV})\right|^2.$$

This pseudo-likelihood function does not include background. Corrections in γ^2_{AV} due to background contribution have been determined using Monte Carlo simulation. Using the likelihood fit corrected for the background contribution ARGUS obtained:

$$\gamma^2_{AV} = 1.043 \pm 0.056 \pm 0.060.$$

Together with the measurement of γ_{AV} by ARGUS in 1990 [8] this leads to a very precise determination of the parameter γ_{AV}:

$$\gamma_{AV} = 1.021 \pm 0.028 \pm 0.030.$$

A scalar-like coupling in τ decays results in an asymmetry in the subprocess $h^\pm \to \pi^\pm\pi^0$. Absense of such an asymmetry leads to an upper limit:

$$\frac{g_S + g_P}{g_V} \cdot f_S \leq 0.35 \ (90\% \ @ \ CL),$$

where f_S is the scalar form factor.

While the shapes of both electron and muon spectra in τ decays are sensitive to the Michel parameter ρ, the η parameter affects only the muon spectrum. The value of η has no effect upon the electron momentum spectrum because the terms in expression (1) containing η also contain the very small factor m_e/m_τ.

In the laboratory frame at $\sqrt{s} = 10$ GeV the dependence of the lepton momentum spectrum from the Michel parameters is substantially smoothed by the Lorentz transformation and hence the sensitivity to Michel parameters is reduced. The optimum sensitivity to the Michel Parameters ρ and η is achieved in the τ rest frame. Partially this sensitivity can be recovered by transformation of the lepton momentum from laboratory frame to a pseudo-rest frame.

In order to perform the Lorentz boost into the τ rest frame, the τ four-momentum has to be known. The τ energy is determined by the beam energy of the storage ring up to initial state radiative corrections. The direction of the τ cannot be exactly reconstructed since the neutrinos escape the detection. It can, however, be inferred from the direction of the system of charged hadrons origninating from the decay of the other τ lepton in the event which is required to decay either into $(3h)^\pm$ or into $(3h)^\pm\pi^0$ system. Due to its relatively high mass this system gives a good approximation to the flight direction of its parent τ and, consequently, of the τ under study since both τ leptons are flying back-to-back. The rest system determined with this approximation can be called "pseudo rest frame". Monte Carlo calculations show that this approximation works well both for $\tau \to (3h)^\pm\nu$ and $\tau \to (3h)^\pm\pi^0\nu$ decays. So one can use all 3-prong τ decay modes in order to enlarge the statistics.

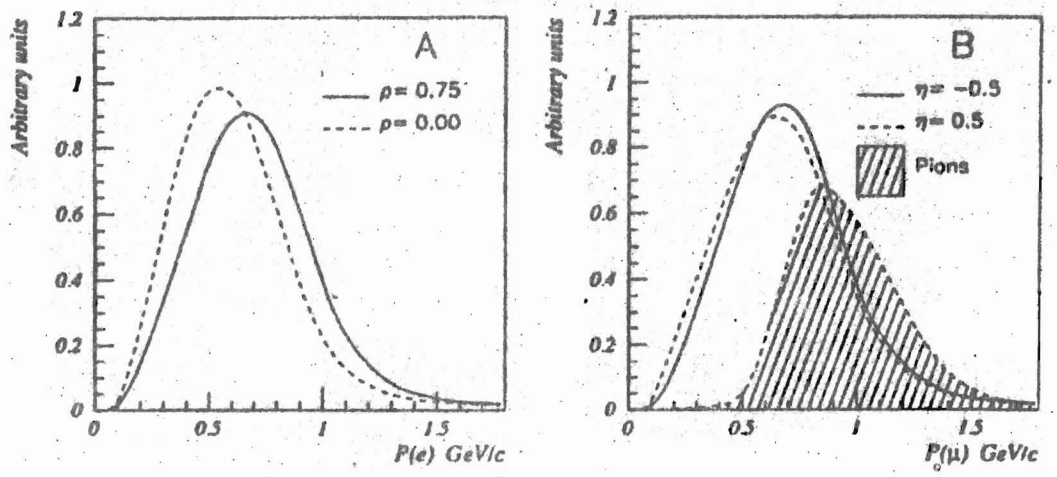

Figure 2: Prediction for the spectrum of electrons with $\rho = 0.75$ and $\rho = 0$ (A) and for muons with $\eta = -0.5$ and $\eta = 0.5$ together with the pion spectrum of the decay $\tau \to \pi\nu_\tau$ (B).

The expected momentum spectrum of electrons from $\tau \to e\bar{\nu}\nu$ decays in the τ pseudo rest frame is shown in Fig. 2A for two values of the parameter ρ.

By a Monte Carlo calculation it was shown that the accuracy of the ρ measurement is higher in the τ pseudo rest frame by a factor of 1.5 in case of the ARGUS data sample. A similar consideration for the η parameter leads to a corresponding gain in precision by a factor of 2. The spectrum of muons from $\tau \to \mu\bar{\nu}\nu$ decays calculated in the pseudo rest frame for $\eta = -0.5$ and $\eta = 0.5$ with fixed value of $\rho = 0.75$ is shown in Fig. 2B.

Muons with momenta below about 1 GeV/c in the laboratory frame can not be used in analysis because of the background from pions from $\tau^- \to \pi^-\nu$ decay. However they can partially be separated from pions in the τ pseudo rest frame. Pion momentum spectrum in the τ rest frame is a delta function. In the pseudo rest frame it transforms into a broad peak (see Fig. 2B). Nevertheless there is still a large region where pions and muons are separated kinematically. Therefore it is possible to use them in analysis of the muon spectrum. This is another advantage of the pseudo rest frame method. Figures 3 and 4 show electron and muon spectra in the pseudo rest frame obtained by ARGUS.

The fit of these spectra with an assumption $\rho_e = \rho_\mu = \rho$ gives

$$\rho = 0.735 \pm 0.036 \pm 0.020.$$

$$\eta = 0.03 \pm 0.18 \pm 0.12.$$

This is the most precise measurement of ρ in $\tau \to e\nu\bar{\nu}$ decay and the first measurement of η using muon momentum spectrum. The obtained results are in good agreement with the SM

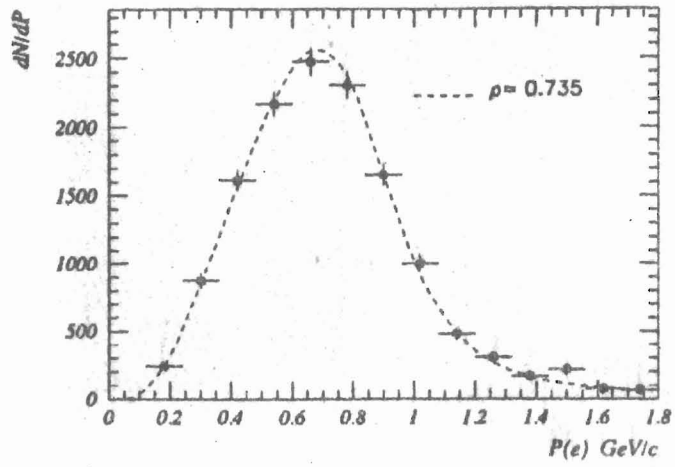

Figure 3: Efficiency corrected electron spectrum in the τ pseudo rest frame (full points) and the result of the fit with the parameter $\rho = 0.735$ (dashed line).

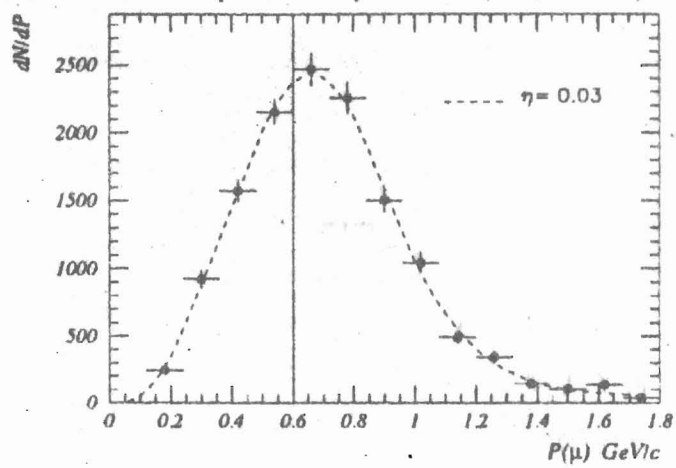

Figure 4: Efficiency corrected muon spectrum in the τ pseudo rest frame (full points) and the result of the fit with parameter $\eta = 0.03$ (dashed line).

predictions.

2 CHARM

2.1 Charm spectroscopy

Charm spectroscopy provides good testing ground for different theoretical approaches including fashionable Heavy Quark Effective Theory (HQET). Excited charm mesons are of special interest because their parameters can be related with parameters of excited beauty mesons which are considered as a potential source of tagged B^0 mesons for CP violation studies.

There should be 12 $L = 1$ charmed mesons: 6 relativly narrow states whose light quark's total angular momentum is $j_l = 3/2$ and 6 very broad states with $j_l = 1/2$.

All these narrow resonances have been observed [11], except for the charmed strange $J^P = 2^+$ meson, designated D_{S2}^{*+}. At this conference CLEO anounced the observation of this meson [12]. Fig. 5 shows the D^0K^+ invariant mass spectrum obtained by CLEO (in fact it shows $M(D^0K^+) - M(D^0) + 1864.5\ MeV/c^2$). The left peak is a feed-down peak from the $D_{s1}(2536)^+$ and the right peak is a new resonance. $D_{s1}(2536)^+$ decays predominantly to D^*K. The Q

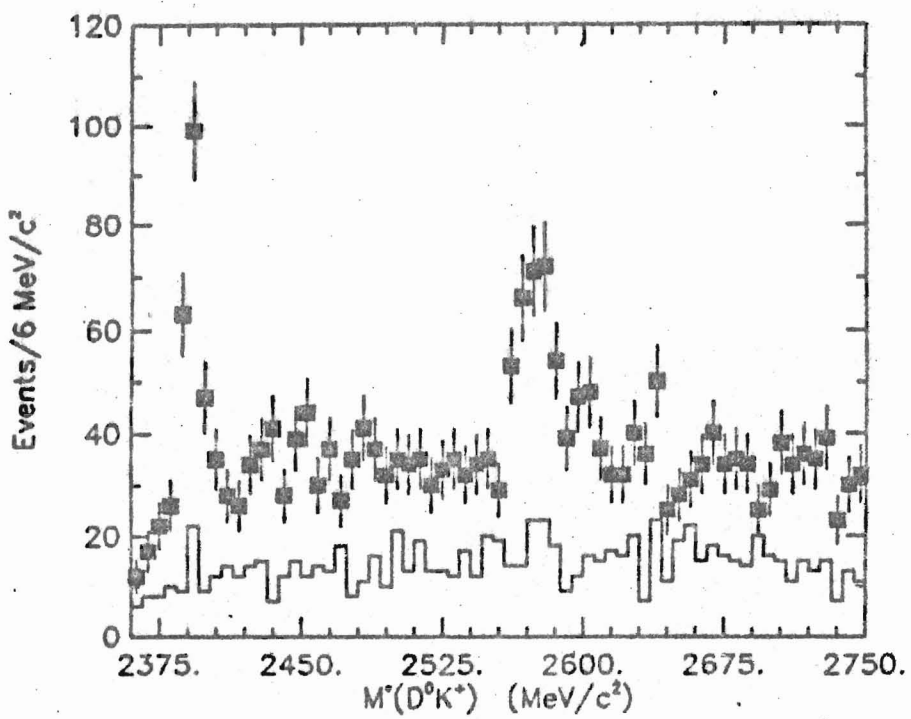

Figure 5: D^0K^+ invariant mass.

value for the $D^{*0} \to D^0\pi^0$ decay is very small, so even though the π^0 is not detected, the peak at about 2380 MeV/c^2 is still very narrow. The width of the new resonance is considerably larger than the detector resolution of about 3 MeV/c^2. Fit gives $M = 2573.3^{+1.7}_{-1.6} \pm 0.8 \pm 0.5\ MeV/c^2$,

and $\Gamma = 15.6^{+6.5}_{-4.8} \pm 3\ MeV/c^2$ where the third error on the mass is due to uncertainty in D^0 mass.

CLEO finds no evidence for another possible decay mode of $D^*_{SJ}(2573)^+ \to D^{*0}K^+$ and sets an upper limit on the ratio of branching ratios:

$$\frac{\mathcal{B}(D^*_{SJ}(2573)^+ \to D^{*0}K^+)}{\mathcal{B}(D^*_{SJ}(2573)^+ \to D^0K^+)} < 0.33$$

at 90% confidence level. This ratio is expected to be small [13] due to limited phase space for the decay to $D^{*0}K^+$. Although spin-parity of a new resonance is not established it must be in the "normal" $0^+,1^-,2^+,3^-$ series (because it decays strongly into D^0K^+). It is natural to identify this state as the D^{*+}_{s2}, the 2^+ partner of the $D_{s1}(2536)^+$.

Fig. 6 illustrates the present knowledge about charmed mesons. Most of the charm excited states have been observed by ARGUS and CLEO.

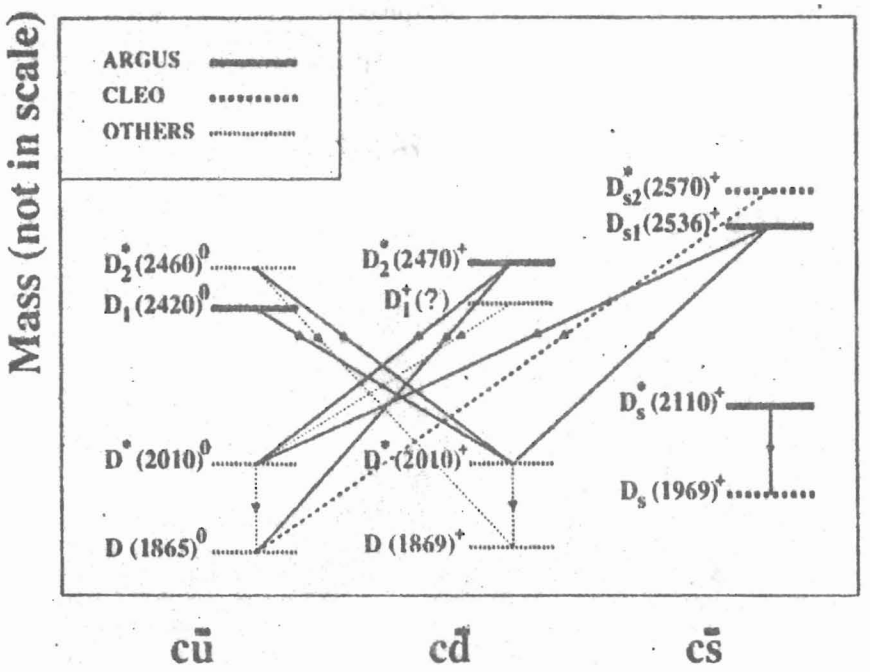

Figure 6: Observed charm mesons (schematic).

Last year at La Thuile ARGUS announced observation of the first excited charmed baryon $\Lambda_c^{*+}(2630)$ [14]. CLEO confirmed this result and observed one more excited baryon [15]. Fig. 7 shows the mass difference $M(\Lambda_c^+\pi^+\pi^-) - M(\Lambda_c^+)$. The right peak corresponds to the $\Lambda_c^{*+}(2630)$ while the left one is a new excited charmed baryon $\Lambda_c^{*+}(2590)$.

The mass difference $M(\Lambda_c^+\pi^+\pi^-) - M(\Lambda_c^+)$ is measured to be $308.0 \pm 0.4 \pm 2.0\ MeV/c^2$. The peak becomes more pronounced (Fig. 7b) if one selects combinations consistent with the

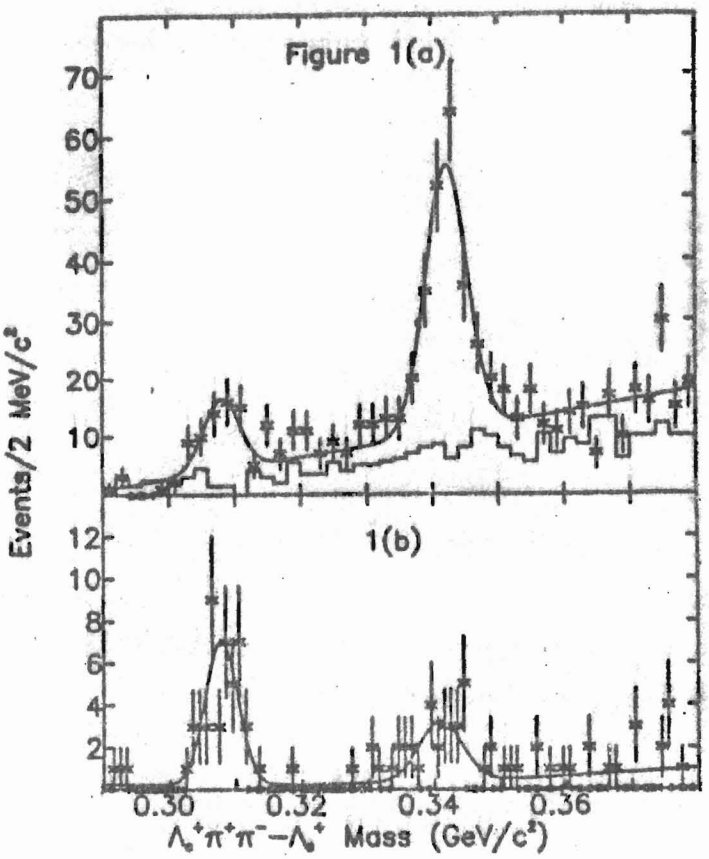

Figure 7: The mass difference $M(\Lambda_c^+\pi^+\pi^-) - M(\Lambda_c^+)$.

$\Sigma_c^{++}\pi^-$ or $\Sigma_c^0\pi^+$ final states.

Theory predicts a large number of excited Λ_c^* and Σ_c^* baryons [16]. For charmed baryon just above threshokl the phase space for $\Lambda_c^+\pi$ decay is much larger than for $\Lambda_c^+\pi^+\pi^-$ decay. Therefore Σ_c^* would decay mainly to $\Lambda_c\pi$ while for Λ_c^* this decay is forbidden by conservation of isospin. Since no signal is observed in the $\Lambda_c\pi$ it is natural to identify $\Lambda_c^{*+}(2530)$ and $\Lambda_c^{*+}(2590)$ with spin 1/2 and 3/2 Λ_c^* states respectively.

2.2 Cabibbo-suppresed D meson decays

Cabibbo suppresed D meson decays are not understood well. For example it is still not clear why $\mathcal{B}(D^0 \to K^+K^-)$ is 2.5 ± 0.4 times larger than $\mathcal{B}(D^0 \to \pi^+\pi^-)$. In the four-body final states situation is reversed:

$$\frac{\mathcal{B}(D^0 \to K^+K^-\pi^+\pi^-)}{\mathcal{B}(D^0 \to \pi^+\pi^-\pi^+\pi^-)} = 0.32 \pm 0.06.$$

A systematic study of all possible Cabibbo suppressed charm decays is probably required to understand the underlying mechanisms.

Table 5: Branching ratios for Cabibbo-suppressed D^0 meson decays in %.

Channel	ARGUS	CLEO	E691
$K^-K^+\pi^+\pi^-$	$0.31 \pm 0.05 \pm 0.04$	0.24 ± 0.08	$0.21^{+0.06}_{-0.05} \pm 0.04$
$K^0_sK^0_s\pi^+\pi^-$	$0.17 \pm 0.05 \pm 0.04$		
$K^{*0}K^-\pi^+$	$0.32 \pm 0.10 \pm 0.07$		
$\bar{K}^{*0}K^+\pi^-$	$0.17 \pm 0.09 \pm 0.07$		
$\phi\pi\pi$	$0.15 \pm 0.04 \pm 0.03$	0.19 ± 0.05	
$\phi\rho^0$	$0.15 \pm 0.04 \pm 0.03$		

Recently ARGUS observed D^0 decays into $K^{*0}K^-\pi^+$, $\bar{K}^{*0}K^+\pi^-$, and $K^0_sK^0_s\pi^+\pi^-$ (see Table 5). Branching ratios are normalized using $\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-) = (7.5 \pm 0.5)\%$. It is interesting to note that $\mathcal{B}(D^0 \to K^{*0}K^-\pi^+)$ is twice larger than $\mathcal{B}(D^0 \to \bar{K}^{*0}K^+\pi^-)$ and that $\mathcal{B}(D^0 \to K^0\bar{K}^0\pi^+\pi^-)$ is comparable to $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^+\pi^-)$.

2.3 Evidence for doubly Cabibbo-suppressed decay $D^0 \to K^+\pi^-$

The reaction $D^0 \to K^+\pi^-$ can occur either through a Doubly Cabibbo Suppressed Decay (DCSD), or through $D^0\bar{D}^0$ mixing, both of which are substantially suppressed in the Standard Model. Any highly suppressed weak decay is of great interest since exotic decay mechanisms could compete with the Standard Model processes. In general, without measuring the decay time distribution, one cannot separate DCSD and mixing.

The best limit on DCSD comes from ARGUS [17]:

$$R = \frac{\mathcal{B}(D^0 \to K^+\pi^-)}{\mathcal{B}(D^0 \to K^-\pi^+)} < 0.009,$$

while the best limit on mixing was obtained by E691 [18]:

$$R < 0.0037.$$

Recently CLEO observed the decay $D^0 \to K^+\pi^-$ using D^0 from the decay $D^{*+} \to \pi^+D^0$ [19]. Fig. 8 shows the D^0 mass in the mass difference $\Delta M = M(K\pi\pi) - M(K\pi) - M(\pi)$ signal region after mass difference sideband subtraction. There is a very clean signal for the decay $D^0 \to K^+\pi^-$.

Very strict cuts have been applied on particle identification, track quality and kinematic properties of the combination in order to remove all possible sources of background from $K^-\pi^+$,

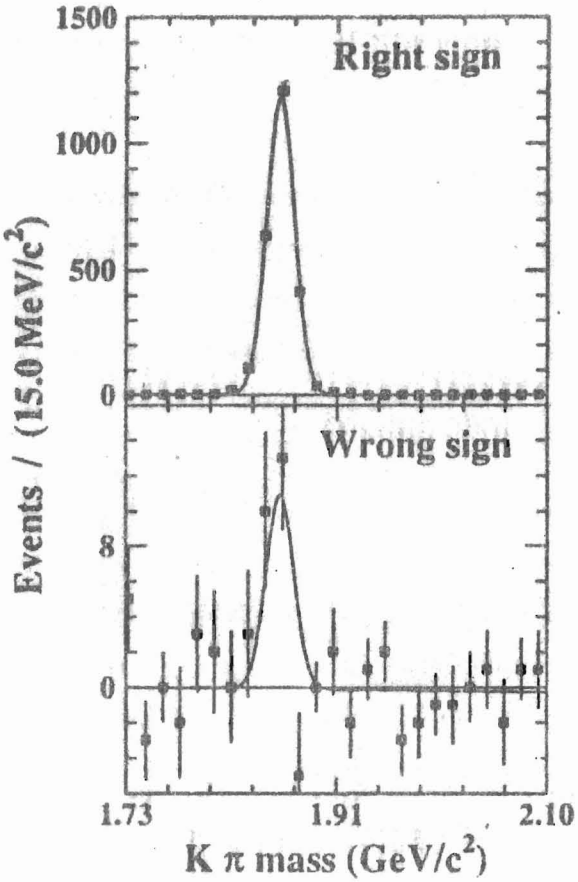

Figure 8: The D^0 mass in the mass difference signal region after mass difference sideband subtraction.

K^+K^-, $\pi^+\pi^-$, $K^-\pi^+\pi^0$, and $K^-\ell^+\nu$ final states. There are 19.1 ± 6.1 signal events in the $D^0 \to K^+\pi^-$ decay. This corresponds to

$$R = 0.0077 \pm 0.0025 \pm 0.0025 \quad \text{or} \quad R = (2.92 \pm 0.95 \pm 0.95)\tan^4\theta_c,$$

where θ_c is the Cabibbo angle. Since E691 limit on $D^0\bar{D}^0$ mixing is smaller than the CLEO result it is natural to interpret it as DCSD. The rate for this decay is somewhat larger than naive expectations of $\tan^4\theta_c$.

2.4 Absolute branching ratios of D meson decays

The $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ decay modes are commonly used for normalizing other D branching ratios. A precise measurement of these modes is necessary to improve

the measurements of many D^0 branching ratios, as well as inclusive and exclusive B meson branching ratios, where the systematic error mainly consists of the uncertainty in $B(D^0 \to K^-\pi^+)$.

Recently ARGUS and CLEO performed measurements of the absolute branching ratios for D mesons using a method similar to the one previously employed by HRS [20] and ALEPH [21]. In this approach, first the total number of D^0 mesons produced in the decay $D^{*+} \to D^0\pi^+$ is determined using a partial reconstruction technique. Subsequent reconstruction of the exclusive decay chains yields the numbers of D decays of interest, thus allowing a measurement of the absolute branching ratios.

D^{*+} mesons are produced copiously in the fragmentation of charmed quarks in the continuum process $e^+e^- \to c\bar{c}$. These D^{*+} have a hard momentum spectrum and therefore their direction coincides closely with the jet axis. The available energy, Q, in the $D^{*+} \to D^0\pi^+$ decay is only 6 MeV so that the angle between the D^* flight direction and the pion momentum vector and hence the angle between the jet axis and the pion momentum vector is also small. Therefore for $D^{*+} \to D^0\pi^+$ we expect $\cos\Theta$ close to unity, where Θ is the angle between the jet axis and the pion momentum vector. The uncorrelated background distribution is expected to have a smooth behaviour near $\cos\Theta = 1$, which can be checked using data. The jet axis can be approximated by the thrust axis of the event.

The $\cos\Theta$ distribution obtained by ARGUS [22] is shown in Fig. 9 for two intervals of pion momenta. The peak in Fig. 9a) is mainly due to pions from $D^{*+} \to \pi^+D^0$ decays. The shape of the peak was obtained from the data using reconstructed D^0 decays into $K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$ and $K^0_s\pi^+\pi^-$. Comparing the number of reconstructed D^0 decays with the total number of entries in the peak in Fig. 9a) ARGUS determined D^0 branching ratios shown in Table 6 together with the results of CLEO and ALEPH.

Table 6: D meson branching ratios in %.

Mode	ARGUS	CLEO	ALEPH
$D^0 \to K^-\pi^+$	$3.41 \pm 0.12 \pm 0.28$	$3.91 \pm 0.08 \pm 0.17$	$3.89 \pm 0.29 \pm 0.16$
$D^0 \to K^-\pi^+\pi^-\pi^+$	$6.80 \pm 0.27 \pm 0.57$		
$D^0 \to K^0_s\pi^+\pi^-$	$5.03 \pm 0.39 \pm 0.49$		
$D^+ \to K^-\pi^+\pi^+$		$10.0 \pm 1.0 \pm 1.2$	

Using their excellent photon detector CLEO has tagged D^+ with π^0 from the decay $D^{*+} \to$

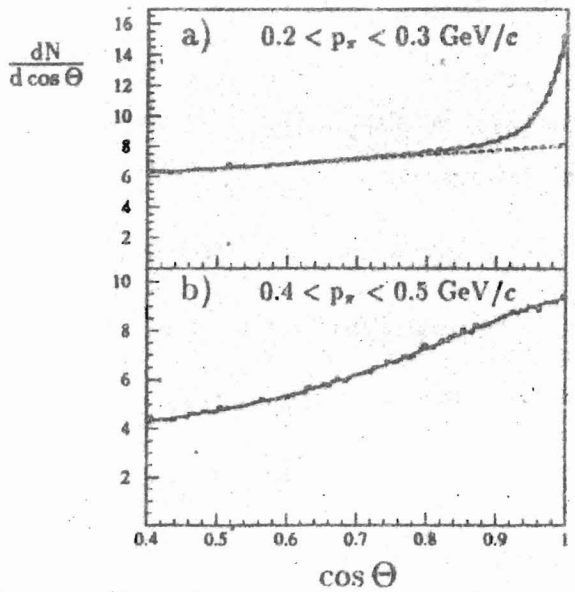

Figure 9: Distribution of $\cos\Theta$ for two intervals of pion momentum.

$\pi^0 D^+$. The obtained branching ratio for the decay $D^+ \to K^-\pi^+\pi^+$ [23] is somewhat larger than the PDG value of $(8.0^{+0.8}_{-0.7})$ % (see Table 6).

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