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RECENT TAU LEPTON AND CHARM RESULTS FROM ARGUS AND CLEO

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RECENT TAU LEPTON AND CHARM RESULTS FROM ARGUS AND CLEO: Preprint ITEP 93-38/

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Recent ARGUS and CLEO τ lepton and charm results are reviewed. Among them are the new measurement of the τ mass, improved limits on m_{ν_τ}, precision measurements of the branching fractions for many τ lepton decays, observation of the decays $\tau^- \to \omega\pi^-\pi^0\nu_\tau$ and $\tau^- \to \eta\pi^-\pi^0\nu_\tau$, and the first determination of the parity-violating Michel parameter ξ_τ. In the charm sector only two results are presented - observation of the first excited charm baryon and measurements of D^0 decays into $\bar{K}^0$ and $\bar{K}^{*0}$.

Fig. - 13, ref. - 26

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1. Tau Lepton

In the Standard Model (SM) the τ lepton and its associated neutrino form a weak doublet and belong to the third generation of quarks and leptons. The existing data generally support this assumption. However, in several cases the agreement between theory and experiment has been far from perfect, leading to many speculations about possible effects beyond the SM.

The leptonic decay rate of the tau is given by

$$\Gamma(\tau^- \to \nu_\tau \ell^- \bar{\nu}_\ell) = \frac{G_\tau G_\ell m_\tau^5}{192\pi^3} f\left(\left(\frac{m_\ell}{m_\tau}\right)^2\right)\left[1 + \frac{3}{5}\frac{m_\tau^2}{m_W^2}\right]\left[1 + \frac{\alpha(m_\tau)}{2\pi}\left(\frac{25}{4} - \pi^2\right)\right], \quad (1)$$

where $f(y) = 1 - 8y + 8y^3 - y^4 - 12y^2 \log y$ accounts for the non-zero masses of the final state leptons. For τ decay to a muon $f(y) = 0.9726$. First order electroweak radiative corrections [1] represented by the terms in square brackets in (1) are very close to unity : 1.0003 and 0.9957 correspondingly.

Using (1) and the analogous formula for muon decay one gets

$$\frac{G_\tau}{G_\mu} = \left(\frac{m_\mu}{m_\tau}\right)^5 \left(\frac{\tau_\mu}{\tau_\tau}\right) \cdot \mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau). \quad (2)$$

All leptons are expected to have a universal weak coupling: $G_\tau = G_\mu = G_e = G_F$. However, inserting the PDG'92 [2] values for masses, lifetimes and branching fractions into Equation (2) gives

$$\frac{G_\tau}{G_\mu} = 0.941 \pm 0.025,$$

about 2.4σ away from the unity ratio expected from lepton universality. The discrepancy is not large but it questions the fundamental assumptions of the SM and has therefore attracted much attention. This so called "Consistency Problem" is illustrated graphically in Fig.1.

Another controversy with the τ is the so called "Completeness Problem" (or "One-Prong Problem") [3]. The sum of the τ exclusive branching fractions, 94.1 ± 1.0 %, was considerably smaller than 100 % if one took the world average values [4].

However, the validity of such an averaging process is questionable. Moreover, a so called global analysis of τ decays [5] does not show any deficit. In a global analysis one first selects a clean sample of $\tau^+\tau^-$ events and then distributes them among the known generic final states.

With more accurate measurements the "Consistensy Problem" practically disappears and the "Completeness Problem" becomes less pronounced. The next sections describe recent ARGUS and CLEO contributions to these studies.

1.1 New value of τ mass

Traditionally the mass of the τ lepton was determined from the behaviour of the total cross section $\sigma(e^+e^- \to \tau^+\tau^-)$ in the threshold region. The four existing measurements lead to an average value of $m_\tau = (1784.1^{+2.7}_{-3.6})$ MeV/c^2 [2].

Recently ARGUS invented a new technique for τ mass determination [6] based on the kinematics of the decay $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$. This technique can be used in principle for other

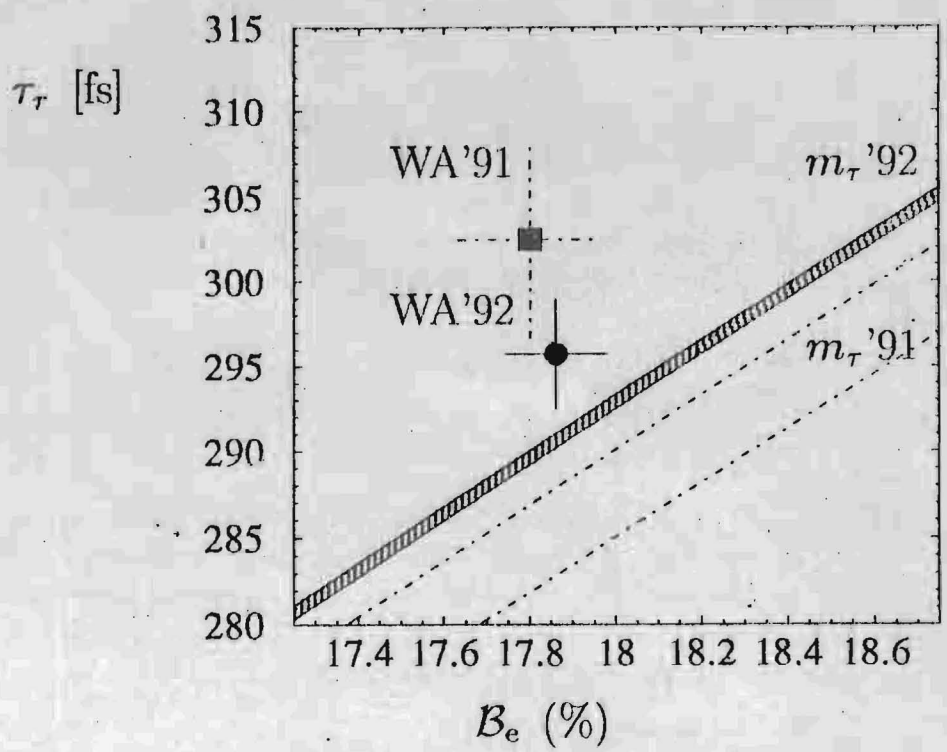

Figure 1: Tests of $\mu-\tau$ universality in 1991 and 1992. Areas between solid and dashed lines correspond to the predictions based on the new and old τ mass measurements, respectively.

τ decays like $\tau^- \rightarrow \pi^-\pi^-\pi^+\pi^0\nu_\tau$ but photon energy resolution in ARGUS is not good enough to make this channel useful.

The τ mass itself cannot be calculated from the measured quantities since the τ flight direction is unknown. However, a τ pseudomass can be derived with the approximation that the flight direction of the 3π system is the flight direction of the τ, i.e. setting $\cos(\vec{p}_\tau, \vec{p}_{3\pi}) = 1$. With $m_\tau^2 = E_\tau^2 - \vec{p}_\tau^2$ and $E_\tau = \sqrt{s}/2$, the nominal beam energy, it follows that only the τ momentum needs to be determined. Using the approximation noted above, a pseudo τ momentum, $p_\tau^* = p_{3\pi} \pm p_{\nu_\tau}$, can be derived from momenta of the 3π system, $p_{3\pi} = |\vec{p}_{3\pi}|$, and the tau neutrino, p_{ν_τ}. The solution $p_\tau^* = p_{3\pi} - p_{\nu_\tau}$ has been discarded since the case where $p_\tau < p_{3\pi}$ is true for only $\approx$ 2% of the τ decays under consideration. The energy of the tau neutrino, E_{ν_τ}, is derived from the energy difference between the τ and the 3π system: $E_{\nu_\tau} = E_\tau - E_{3\pi}$. With $p_{\nu_\tau} = \sqrt{E_{\nu_\tau}^2 - m_{\nu_\tau}^2}$ and $m_\tau^{*2} = E_\tau^2 - p_\tau^{*2}$ it follows that:

$$m_\tau^{*2} = 2E_\tau E_{3\pi} - 2E_{3\pi}^2 + m_{3\pi}^2 + m_{\nu_\tau}^2 - 2p_{3\pi}\sqrt{(E_\tau - E_{3\pi})^2 - m_{\nu_\tau}^2}.$$

The mass of the tau neutrino is known to be very small: $m_{\nu_\tau} < 35$ MeV/c^2 (95% CL)[7]. The scale of its effect on the pseudomass determination is set by comparison with the other terms $m_{3\pi}^2$ and $(E_\tau - E_{3\pi})^2$. Since the 3π system is formed by the decay of an a_1 meson [8], the $m_{3\pi}$ takes values above 0.9 GeV/c^2, i.e. large compared to 35 MeV/c^2. Due to the restriction of the choice for p_τ^* to $p_{3\pi} + p_{\nu_\tau}$, the a_1 meson is emitted opposite to the τ direction of flight (as seen from the τ rest frame) for events where the approximation $\cos(\vec{p}_\tau, \vec{p}_{3\pi}) = 1$ holds true. Since almost no events with $m_{3\pi}$ masses close to the mass of the τ lepton have been found, the difference between τ and 3π energies is larger for the majority of events with $m_\tau^* \approx m_\tau$, so that here too $(E_\tau - E_{3\pi}) \gg 35$ MeV/c^2. Therefore, a finite but small tau neutrino mass has only a marginal influence on the determination of

m_τ and can be neglected. Hence, m_τ^{*2} can be written as:

$$m_\tau^{*2} = 2(E_\tau - E_{3\pi}) \cdot (E_{3\pi} - p_{3\pi}) + m_{3\pi}^2.$$

The observed pseudomass spectrum is shown in Fig.2 together with the Monte Carlo prediction for the $m_\tau = 1.7841$ GeV/c^2.

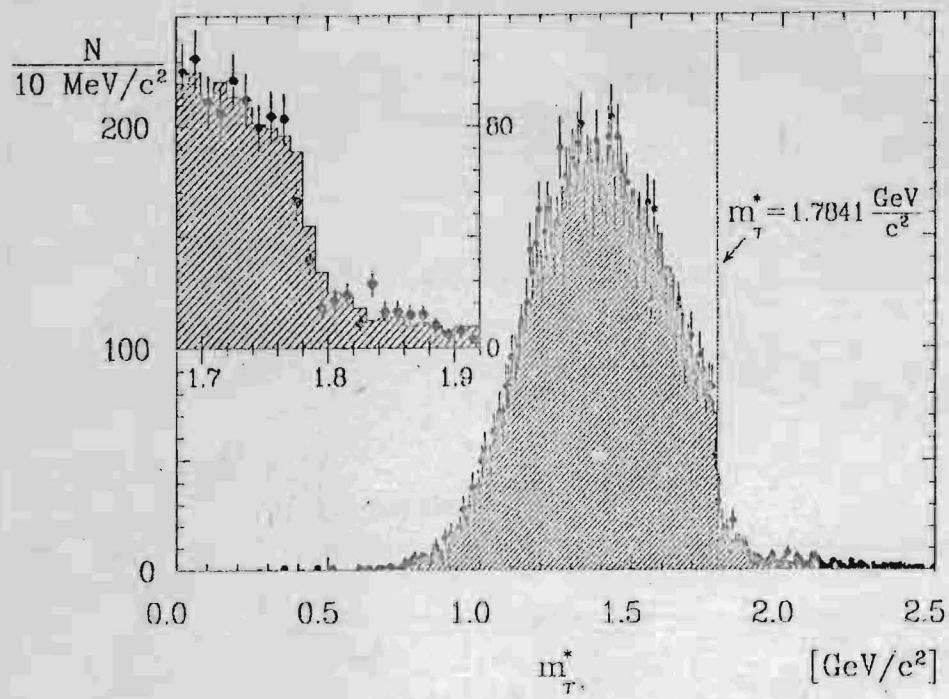

Figure 2: Measured 3π pseudomass spectrum compared with the results from a Monte Carlo calculation (hatched histogram).

The data exibit a sharp threshold behaviour in the region close to the nominal value of the τ mass. The tail above the nominal τ mass is due to initial-state radiation processes which effectively reduce the τ energy. Since the beam energy is used in calculation of the pseudomass, the true τ energy is overestimated, leading to higher values of m_τ^*. The position of the pseudomass threshold is directly related to the mass of the τ lepton. The threshold for the data sample appears to lie below the Monte Carlo expectation for $m_\tau = 1.7841$ GeV/c^2 (enlarged section of Fig.2), indicating that the τ mass is smaller than previously measured.

The τ mass has been obtained by fitting the measured m_τ^* spectrum using a Monte Carlo calculation to determine the expected shape for arbitrary τ masses. Such a fit gives a τ mass of:

$$m_\tau = (1776.3 \pm 2.4 \pm 1.4) \text{ MeV}/c^2,$$

where the main systematic error is due to the absolute momentum scale uncertainty of 0.15%. This value is 7.8 MeV/c^2 lower than the previous world average. This is quite a large shift and it has several consequences.

The downward shift in the τ mass leads to an improved upper limit on the mass of the τ neutrino:

$$m_{\nu_\tau} < 31 \text{ MeV}/c^2$$

at a 95 % confidence level [6]. The ARGUS value of m_τ is in much better agreement with the expectations from lepton universality (see Eq. (2)) than the previous measurements

Shortly after the ARGUS result the BES Collaboration [9] presented their new high precision measurement of the τ mass:

$$m_\tau = 1776.9^{+0.4}_{-0.5} \pm 0.2 \text{ MeV/c}^2 \tag{3}$$

based on the classical method of the cross section measurement near the $\tau^+\tau^-$ threshold. They observed 7 $e^+\mu^-$ events near the threshold with an estimated background of only 0.12 events. The BES value of the τ mass coincides practically with the ARGUS result and has much better accuracy.

One should remember, however, that the BES experiment has low statistics and the errors are not Gaussian. Inspection of the likelihood function [10] demonstrates that at a 3σ level more than 3 MeV/c^2 shifts in m_τ are allowed by the data. This is much larger than naive expectations from the simplified formulae (3).

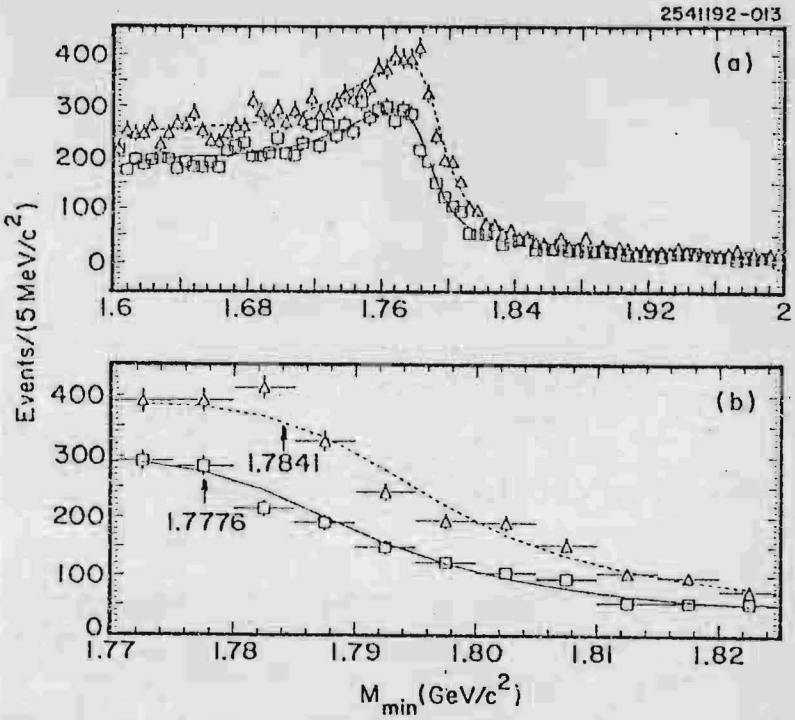

Figure 3: The $M_{\min}$ distribution and fit for the data (squares,solid curve) and for the Monte Carlo (triangles,dashed curve). Monte Carlo was generated with a mass of 1784.1 MeV/c^2 and has an arbitrary vertical scale.

CLEO has measured the τ mass [11] using the fact that the τ^+ and τ^- are produced in opposite directions. Events were selected in which each τ decays hadronically to one charged particle and 0, 1 or 2 π^0s. At least one π^0 was required in the event. A total of 35255 combinations were selected. In the process $e^+e^- \to \tau^+\tau^-$ the two τ directions must lie on cones around the hadron directions. In the absence of initial state radiation the τ directions must lie on the intersection of one cone and the parity invertion of the other cone. When m_τ decreases the cones shrink and finally just touch each other. This degenerate solution defines the "minimum kinematically allowed τ mass" for the event, $M_{\min}$. The experimental distribution of $M_{\min}$ is shown in Fig. 3. It shows a sharp step near $m_\tau$which allows its precise determination. The fit of the Monte Carlo shape to the data gives:

$$m_\tau = 1777.8 \pm 0.7 \pm 1.7 \text{ MeV/c}^2$$

in excellent agreement with the ARGUS and BES results. The systematic error is dominated by the uncertainty in the absolute energy scale as in the ARGUS method.

The existing measurements of m_τ are shown in Fig. 4. The new average (dominated by the BES result):

$$m_\tau = 1777.1 \pm 0.5 \text{ MeV/c}^2$$

differs considerably from the older measurements.

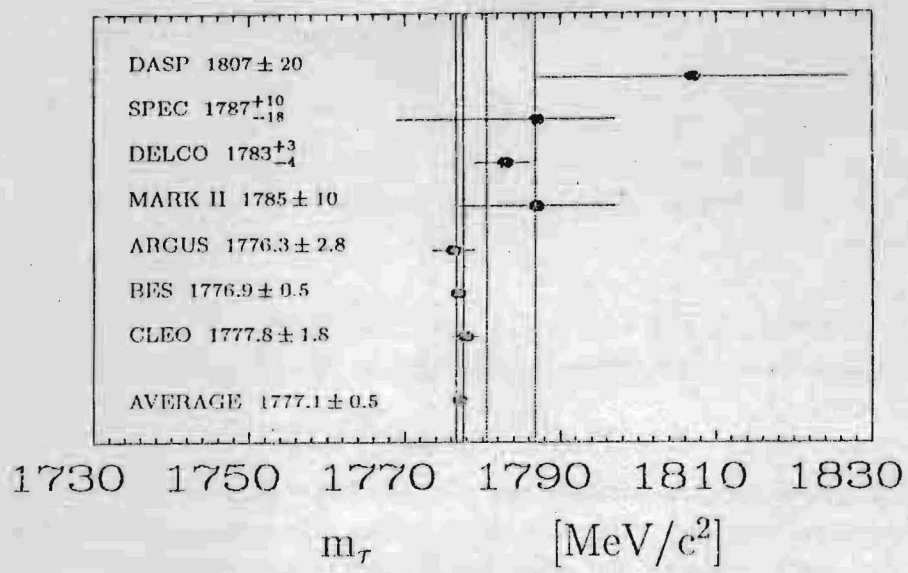

Figure 4: Compilation of τ mass measurements.

CLEO also obtained a new limit on the τ neutrino mass. From the analysis of the pion system mass distributions in the decays $\tau^- \to (5\pi)^- \nu_\tau$ they obtained [12]:

$$m_{\nu_\tau} < 32.6 \text{ MeV/c}^2$$

at 95 % confidence level.

1.2 Measurement of the tau lepton electronic branching fraction

The importance of $\mathcal{B}(\tau^- \to e^- \nu_e \bar{\nu}_\tau)$ for tests of lepton universality has already been discussed in the introduction. In addition the precise knowledge of this branching fraction allows one to calculate branching fractions for many τ decays ($\pi\nu_\tau, K\nu_\tau, K^*\nu_\tau, \rho\nu_\tau, 4\pi\nu_\tau, \ldots$) on the basis of low energy data.

In order to achieve a high accuracy in $\mathcal{B}_e$ CLEO has studied events in which both τ leptons decay into $e\nu\bar{\nu}$ [13]. In this case a square of the branching fraction $\mathcal{B}_e^2$ is measured and hence the accuracy in $\mathcal{B}_e$ is improved by a factor of $1/\sqrt{2}$. In addition this method does not depend on other branching fractions.

The CLEO detector is well suited for investigation of this channel. The CLEO electromagnetic calorimeter has an excellent energy resolution

$$\frac{\sigma_E}{E}(\%) = \frac{0.35}{E^{0.75}} + 1.9 - 0.1E,$$

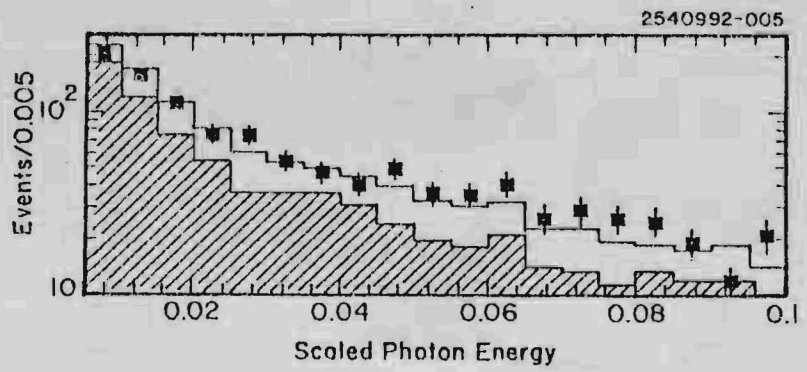

Figure 5: Distribution of scaled photon energy for the highest energy shower per event in data (squares), Monte Carlo with decay radiation included (upper histogram) or excluded (hatched histogram).

low noise, and covers 98 % of the solid angle. This has enabled CLEO to obtain a measurement with very low systematic error. A large accumulated luminosity leaded to a small statistical error:

$$\mathcal{B}_e = 17.49 \pm 0.15 \pm 0.22\ \%.$$

This is the most accurate measurement of the τ lepton branching fraction.

CLEO even managed to observe photon radiation in this decay for the first time. This is illustrated in Fig. 5 which shows the measured photon energy spectrum. The number of photons and their energy spectrum in the di-electron sample agree with Monte Carlo only if τ decay radiation is included.

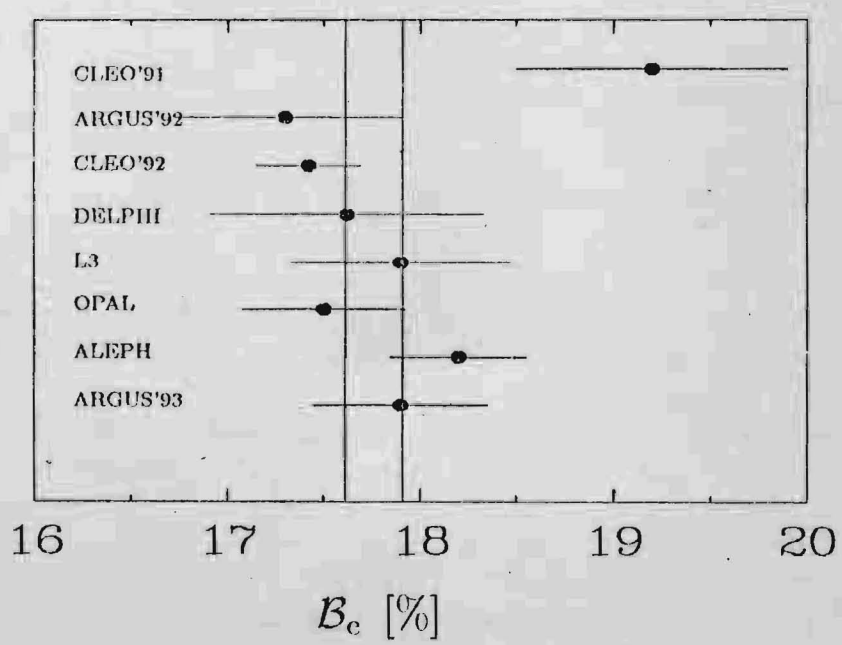

Figure 6: Recent measurements of the tau electronic branching ratio

ARGUS also has new measurement of the τ leptonic branching fraction.Events in which

one τ decays into $e\nu\bar{\nu}$ and the other into $\mu\nu\bar{\nu}$ were studied. Assuming $e-\mu$ universality they obtain

$$\mathcal{B}_e = 17.9 \pm 0.2 \pm 0.4\ \%.$$

Fig. 6 shows the most accurate results on $\mathcal{B}_e$. The new world average is now [14]:

$$\mathcal{B}_e = 17.76 \pm 0.15\ \%.$$

Using measurements of $\mathcal{B}_\mu$ and assuming $e-\mu$ universality one can improve the accuracy in $\mathcal{B}_e$:

$$\mathcal{B}_e = 17.86 \pm 0.12\ \%.$$

1.3 Test of lepton universality

Both ARGUS [17] and CLEO [18] have measured the τ lifetime. However, the world average is dominated now by the LEP experiments [14]:

$$\tau_\tau = 295.7 \pm 3.2\ \text{fs}.$$

The new values of $m_\tau, \mathcal{B}(\tau^- \to e^-\nu_e\nu_\tau)$, and τ_τ are in much better agreement with the predicton (2) based on the lepton universality. This can be seen clearly in Fig. 1. Thus the "Consistency Problem" has practically disappeared.

1.4 Tay decays involving π^0 or η mesons

Accurate measurements of τ decays with photons in the final state represent an experimental challenge. The CLEO II detector is well suited to such studies because of its electromagnetic calorimeter which has excellent energy resolution and fine segmentation.

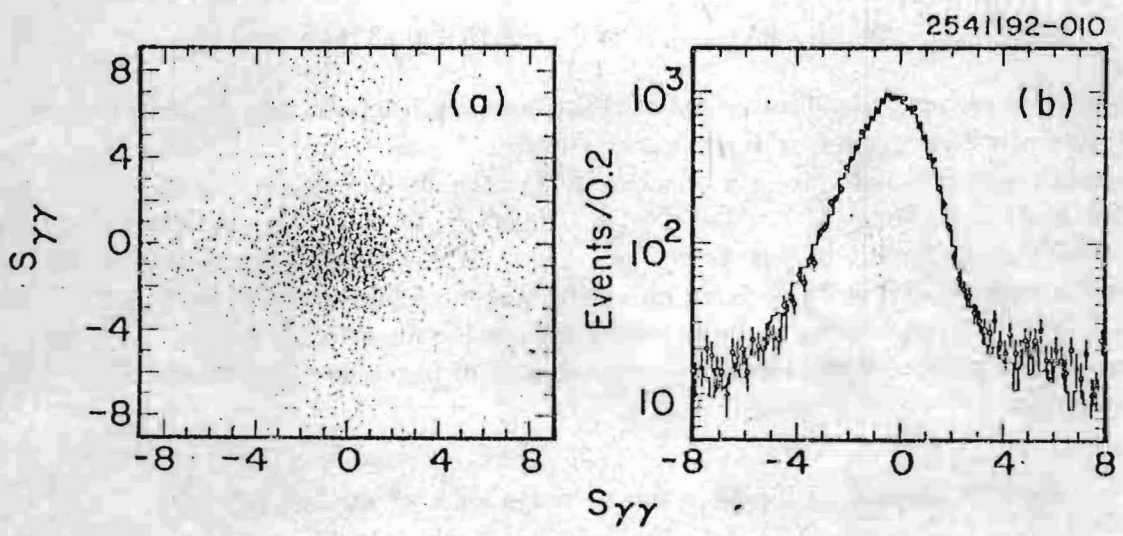

Figure 7: (a)The quantity $s_{\gamma\gamma} \equiv (m_{\gamma\gamma} - m_{\pi^0})/\sigma_{\gamma\gamma}$ for one photon pair versus the other (b)The $s_{\gamma\gamma}$ for data (squares) and the Monte Carlo (histogram).

The decay $\tau \to h^-\pi^0\nu_\tau$ was studied by CLEO using the $h^+\pi^0\nu_\tau$ vs. $h^-\pi^0\nu_\tau$ topology. The $h^-\pi^0\nu_\tau$ mode is dominated by $\rho^-\nu_\tau$ but also receives contributions from $K^{*-}\nu_\tau, \rho^{-\prime}\nu_\tau$,

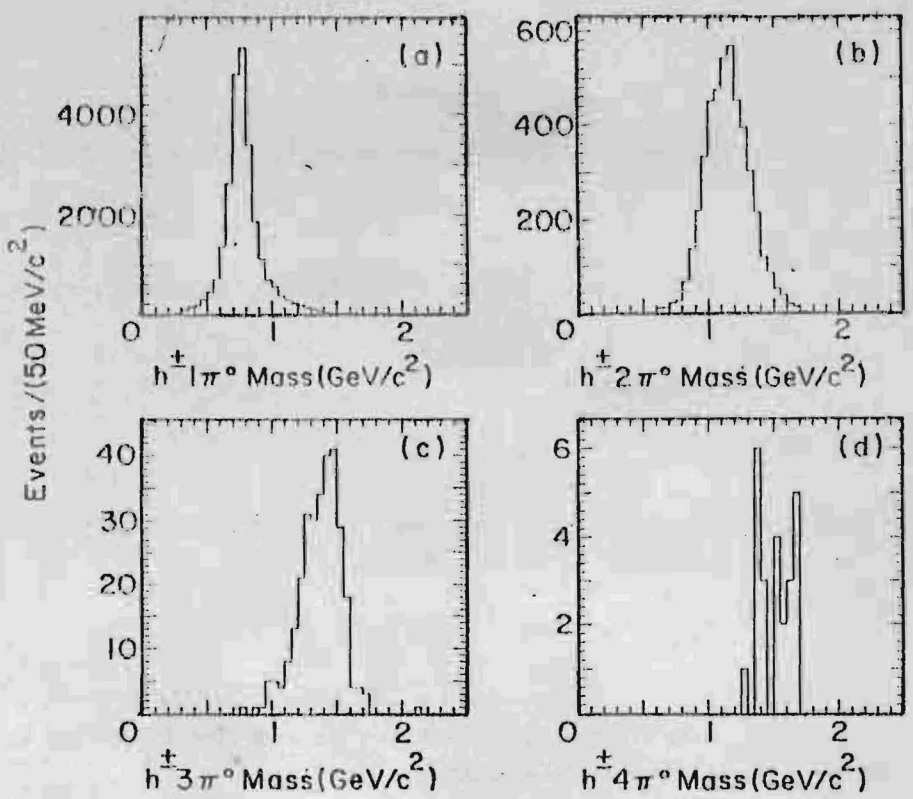

Figure 8: Invariant $\pi^- n\pi^0$ mass spectra with one,two,three and four reconstructed π^0's.

and non-resonant $h^-\pi^0\nu_\tau$ modes. Fig. 7 shows how well the $\pi^0 - \pi^0$ signal is seen in the data. There is only a 4.5 % background, estimated from the sidebands. There are 6522 events left after background subtraction which leads to [10]

$$\mathcal{B}(\tau^- \to h^-\pi^0\nu_\tau) = 24.83 \pm 0.15 \pm 0.53 \quad \%.$$

This is the most precise measurement of this branching fraction. The main contribution to the systematic error comes from the uncertainty in the efficiency.

To study multi-π^0 single-prong τ decays CLEO tagged the second τ lepton using leptonic ($e\nu\bar{\nu}, \mu\nu\bar{\nu}$) or 3-prong ($3h^\pm [\pi^0] \nu$) decays. Clear signals are observed in four channels $h^-\pi^0\nu_\tau, h^-\pi^0\pi^0\nu_\tau, h^-3\pi^0\nu_\tau$, and $h^-4\pi^0\nu_\tau$ (see Fig.8) [15]. The corresponding branching fractions are summarized in Table 1 assuming the world average value of 24.26 ± 0.4 % for $\mathcal{B}(\tau^- \to h^-\pi^0\nu_\tau)$. The last error in these results reflects the uncertainty in $\mathcal{B}(\tau^- \to h^-\pi^0\nu_\tau)$. These results are more precise than the world averages of previous experiments. This is the first measurement of $\tau^- \to h^-4\pi^0\nu_\tau$.

Table 1: Branching fractions for τ decays with π^0 mesons (CLEO).

Decay Mode	Branching fraction [%]
$h^-\pi^0\nu_\tau$	$24.83 \pm 0.15 \pm 0.53$
$h^-2\pi^0\nu_\tau$	$8.44 \pm 0.15 \pm 0.39 \pm 0.14$
$h^-3\pi^0\nu_\tau$	$1.02 \pm 0.07 \pm 0.10 \pm 0.02$
$h^-4\pi^0\nu_\tau$	$0.15 \pm 0.05 \pm 0.05 \pm 0.01$

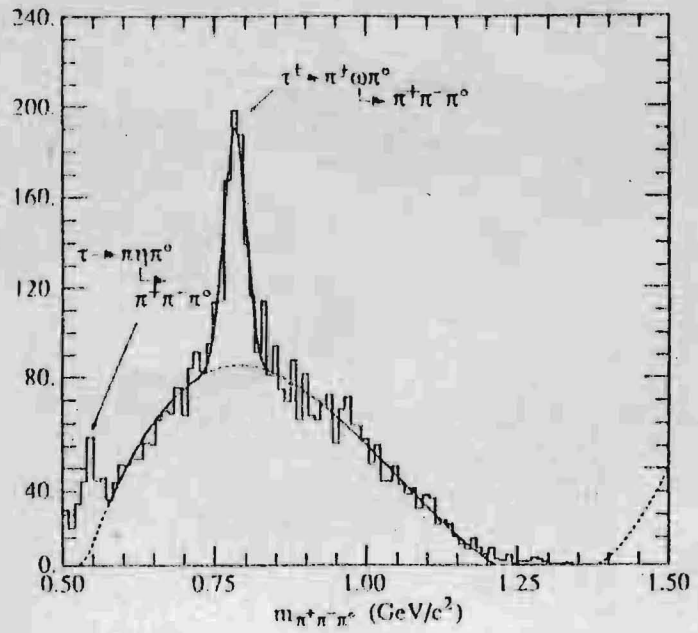

Figure 9: Mass distribution for $\pi^+\pi^-\pi^0$ in the decays $\tau \to 3\pi^{\pm}2\pi^0\nu_\tau$.

Another new mode discovered by CLEO is $\tau^- \to \pi^+\pi^-\pi^-\pi^0\pi^0\nu_\tau$ [14]. It has an unexpectedly large branching fraction of 0.54 ± 0.10 %. For the all-charged mode with 5π the branching fraction is only 0.056 ± 0.016 %. This result demonstrates that new large decay modes can still be discovered. The invariant mass spectrum for $\pi^+\pi^-\pi^0$ combinations in this decay shows a beatiful ω signal (see Fig.9) - again the first observation.

Tau decays into final states with η mesons were often considered as candidates for solving the "one-prong problem". Recently CLEO observed the first channel with an η meson - $\tau^- \to \eta\pi^-\pi^0\nu_\tau$ [16]. The quality of the η and π^0 reconstruction is illustrated in Fig.10. The branching fraction for this decay

$$\mathcal{B}(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = 0.17 \pm 0.02 \pm 0.02 \ \%$$

agrees reasonably well with the CVC prediction of 0.13 ± 0.02 %.

CLEO has looked for several other decays with η mesons and did not observe them. The obtained upper limits are summarized in Table 2. These upper limits are stringent enough to exclude the possibility that such decays could contribute considerably to the one-prong topology.

Table 2: Upper limits on branching fractions in units of 10^{-4} at 95 % CL.

Decay Mode	
$\tau^- \to \eta\pi^-\nu_\tau$	3.4
$\tau^- \to \eta K^-\nu_\tau$	4.7
$\tau^- \to \eta\pi^-\pi^0\pi^0\nu_\tau$	4.3
$\tau^- \to \eta\eta\pi^-\nu_\tau$	1.1
$\tau^- \to \eta\eta\pi^-\pi^0\nu_\tau$	2.0

The new precise measurements by CLEO and ALEPH lead to the sum of measured τ

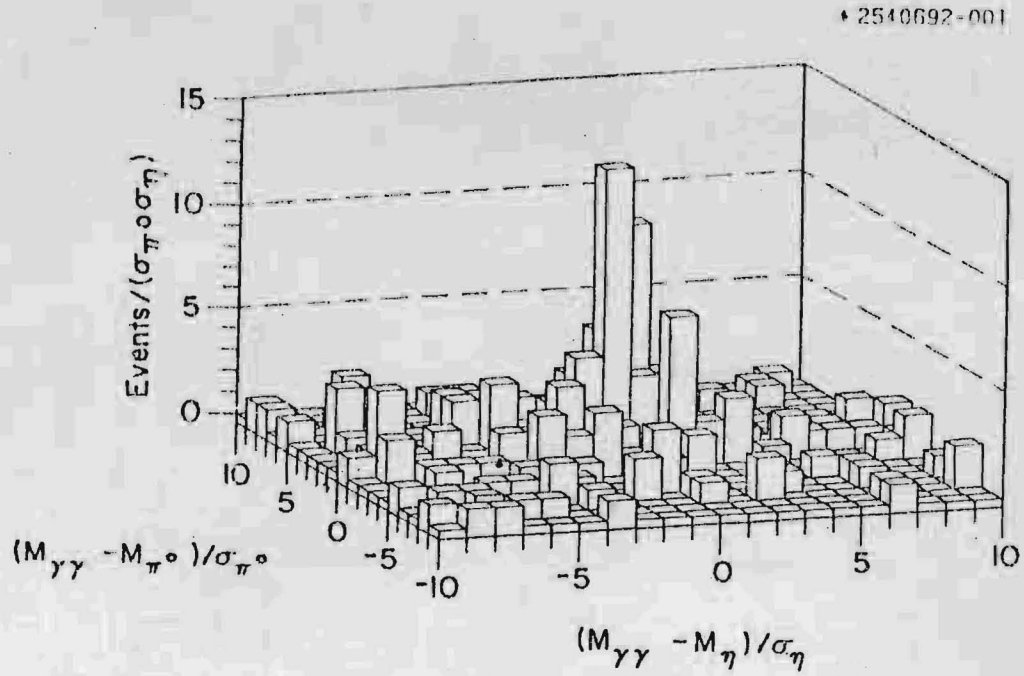

Figure 10: Signal for $\pi^-\pi^0\eta$ hadronic state in τ decays with $\eta \to \gamma\gamma$.

branching fractions close to 100 %:

$$\sum B_\tau = 97.4 \pm 0.9\ \%$$

if one takes world average values [14]. However, CLEO results are systematically lower than the ALEPH values and there is still a lot of work to be done before the "Completeness problem" is settled conclusively. Moreover, it is possible to say that the completeness problem indeed existed to some extent. At least one unexpected channel with a large branching ratio was observed - the decay $\tau^- \to \pi^+\pi^-\pi^-\pi^0\pi^0\nu_\tau$.

1.5 First determination of the Michel parameter ξ_τ

A completely general Lorentz structure of τ decay is described by 10 complex constants [19]. These can be related to the Michel parameters [20]. The Lorentz structure of τ decay is not well tested yet. The world average for the Michel parameter ρ [2], $\rho = 0.727 \pm 0.033$, agrees with the $V - A$ prediction of 0.75 and the observation of parity violation in τ decays [21] demonstarates that the τ-neutrino is indeed left-handed. Recently ARGUS has determined for the first time the parity-violating Michel parameter ξ_τ.

In the τ rest frame, neglecting radiative corrections, the momentum spectrum of the charged decay lepton ℓ is given by

$$\frac{d\Gamma_{\tau\to\ell\nu\bar{\nu}}}{d\Omega dx_\ell} \propto x_\ell^2 \cdot \{12(1-x_\ell) + \rho_\tau \cdot (\frac{32x_\ell}{3} - 8) + \eta_\tau \cdot \frac{m_\ell}{m_\tau} \cdot \frac{24(1-x_\ell)}{x_\ell} - P_\tau \cdot \xi_\tau \cdot \cos\vartheta \cdot \left[4(1-x_\ell) + \delta_\tau \cdot (\frac{32x_\ell}{3} - 8)\right]\},$$

where $x_\ell = p_\ell/p_\ell^{max}$ is the scaled lepton momentum, P_τ the τ polarization, and ϑ the angle between the τ spin and the lepton momentum. With unpolarized τ-leptons, or integrating over the full ϑ range, the spectrum depends only on ρ_τ and η_τ. Measurements of the other two Michel parameters require polarized taus. Electron-positron annihilation produces τ pairs with simple correlation between the two τ spins. At high energies, there are only

events with both spins parallel, either ($P_{\tau^+} = +1, P_{\tau^-} = -1$) or ($P_{\tau^+} = -1, P_{\tau^-} = +1$). Their probabilities are equal as long as the Z^0 contribution is negligible. This spin structure correlates the two charged lepton momenta in $\tau^+\tau^- \to (\mu^\pm\nu\bar{\nu})(e^\pm\nu\bar{\nu})$ events if both $\xi_{\tau\to e}$ and $\xi_{\tau\to\mu}$ are non-zero. An observation of e and μ momentum correlation gives a measurement of the product $\xi_{\tau\to e} \cdot \xi_{\tau\to\mu}$.

Using the momentum correlation between $\vec{p}_\mu$ and $\vec{p}_e$ and assuming $\xi_{\tau\to e} = \xi_{\tau\to\mu} = \xi_\tau$ ARGUS obtained

$$|\xi_\tau| = 0.90 \pm 0.13 \pm 0.08.$$

This value agrees with $V - A$ ($\xi_\tau = +1$) and $V + A$ ($\xi_\tau = -1$) couplings but excludes V or A variants ($\xi_\tau = 0$). Measurements at LEP demonstrate that the sign of ξ_τ is positive [22] in agreement with the $V - A$ prediction.

2. CHARM

ARGUS and CLEO have many new results on charm. They address different aspects of charm physics. In this talk only two examples will be presented - the observation of the first excited charm baryon and a study of D^0 decays into the final states with $\bar{K}^0$ and $\bar{K}^{*0}$.

2.1 Observation of the first excited charm baryon

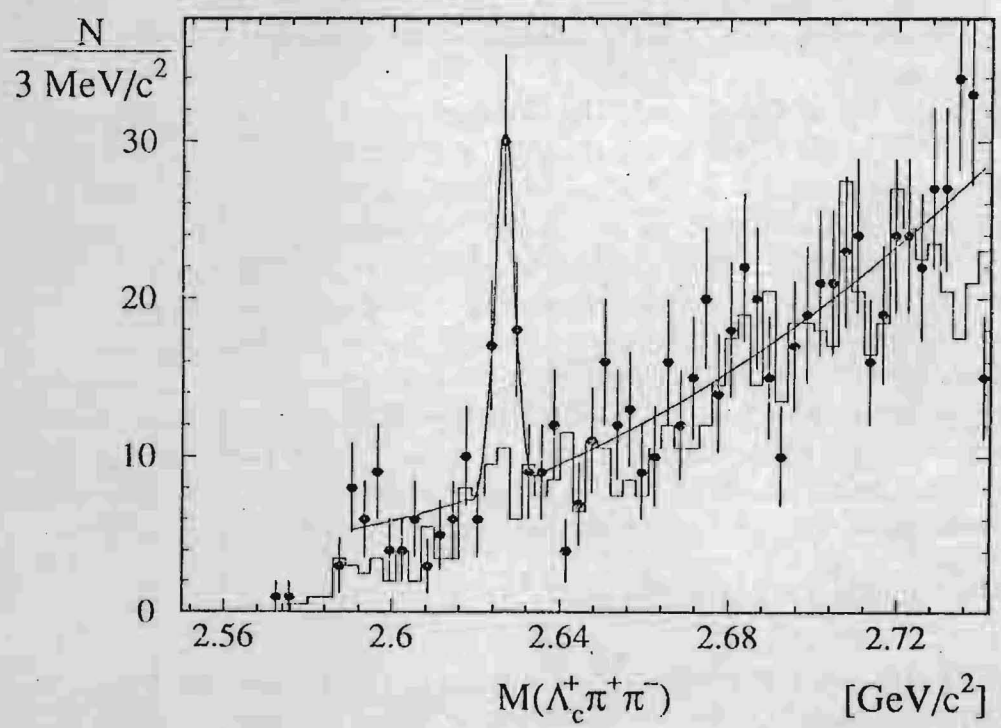

Figure 11: $\Lambda_c^+\pi^+\pi^-$ invariant mass distribution (points) and the fit results. Histogram represents sidebands of Λ_c^+.

All ground state $J^P = \frac{1}{2}^+$ charm baryons have already been observed and their properties studied in detail [2, 23]. Recently the ARGUS collaboration obtained evidence for the charm baryon in the $\Lambda_c^+\pi^+\pi^-$ final state. The Λ_c^+ baryon was reconstructed in four

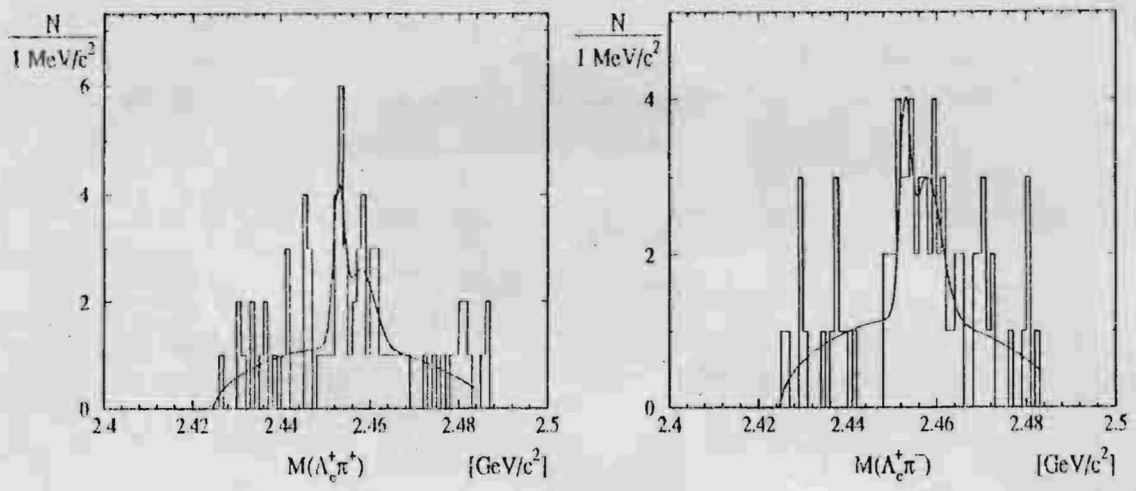

Figure 12: Invariant mass distributions for $\Lambda_c^+\pi$ combinations from the signal. The solid curves represent fits described in the text.

decay modes - $pK^-\pi^+$, $p\bar{K}^0$, $\Lambda^0\pi^+$, and $\Lambda^0\pi^+\pi^+\pi^-$. The resulting $\Lambda_c^+\pi^+\pi^-$ invariant mass spectrum for $x_p > 0.5$ is shown in Fig. 11.

A narrow peak at a mass of $2626.6 \pm 0.5 \pm 1.5$ MeV/c^2 is clearly visible while for Λ_c^+ sidebands the distribution is smooth. It was verified using Monte Carlo that the peak can not be a reflection from Σ_c or other charm particles. The width of the peak is consistent with the detector resolution. This leads to an upper limit on the natural width of less than 5 MeV at 90 % confidence level.

Three possible channels could contribute to the observed signal: non-resonant $\Lambda_c^+\pi^+\pi^-$ production, decays to $\Sigma_c^{++}\pi^-$ and $\Sigma_c^0\pi^+$, followed by $\Sigma_c \to \Lambda_c^+\pi^\pm$. Fig. 12 shows the $\Lambda_c^+\pi^+$ and $\Lambda_c^+\pi^-$ invariant mass spectra for $\Lambda_c^+\pi^+\pi^-$ combinations from the signal region. In these spectra one expects to see signals from Σ_c^{++} and Σ_c^0 correspondingly. Unfortunately the phase space is very limited and Σ_c^0 decays lead to a reflection slightly above the Σ_c^{++} mass and vice versa. The fit which takes into account these reflections demonstrates the existence of Σ_c^{++} or Σ_c^0 baryons in more than one half of the signal events.

The x_p distribution for the signal was found to be very hard - typical for charm baryons.

The observed properties of the signal agree with the hypothesis that this is an excited Λ_c^{*+} baryon. The small width is due to the reduced phase space for the decays $\Lambda_c^{*+} \to \Sigma_c\pi$. Excited Σ_c baryons would decay into $\Lambda_c^+\pi$ and would have much larger width. The mass of a new charm baryon agrees with the theoretical predictions for exited Λ_c^+ states [24].

2.2 Study of D^0 decays into $\bar{K}^0$ and $\bar{K}^{*0}$

D meson decays are still not well understood. There are several theoretical approaches which explain semiquantitatively the lifetime difference between D^+ and D^0. However, there is still a controversy about the role of different mechanisms which can cause the lifetime difference. In particular the contribution from W-exchange diagrams and the role of final state interactions (FSI) are not known. In order to solve these problems one needs measurements of many D decays.

The decays of the D^0 into $\bar{K}^0$ or $\bar{K}^{*0}$ and non-strange neutrals π^0, η or η' are of special interest because they can occur either through "internal W-emission" or "W-exchange" diagrams, as shown in Fig.13. CLEO has performed new measurements of all these decays

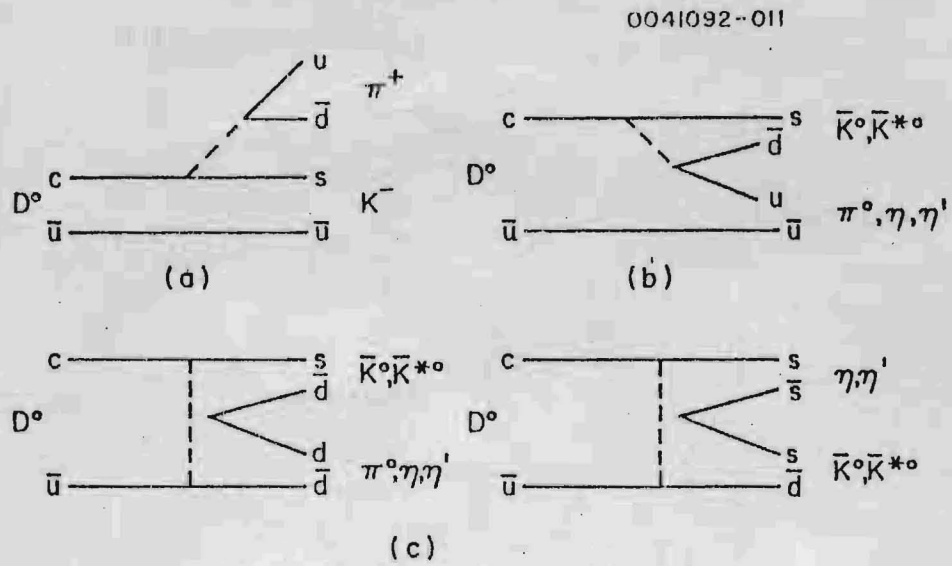

Figure 13: Feynman diagrams for (a) external W process, (b) internal W process, (c) W-exchange process.

[25]. The results are summarized in Tables 3,4 [25] and compared with theoretical predictions. Several theoretical approaches are excluded by the data and none describes all the

Table 3: Branching fractions for D^0 decays with $\bar{K}^0$ [%]

	$\bar{K}^0\pi^0$	$\bar{K}^0\eta$	$\bar{K}^0\eta'$
CLEO	$2.8 \pm 0.1 \pm 0.6$	$0.88 \pm 0.09 \pm 0.16$	$2.0 \pm 0.15 \pm 0.42$
ARGUS	$2.2 \pm 0.3 \pm 0.5$	< 2.7(90 % CL)	$2.4 \pm 0.8 \pm 0.6$
E691	$5.7 \pm 1.0 \pm 1.2$		
Theory:			
WSB w/o FSI	1.0	0.4	0.15
WSB w FSI	Input 2.5 %		
1/N,N=∞	2.1	0.8	
1/N,N=3	0.2	0.1	
QCD sum rules	1.5	0.4	1.2

data perfectly. Obviously a lot of theoretical and experimental work must be done before D decays are quantitatively understood. Lipkin [26] has pointed out that the presence of $W-$exchange diagrams should lead to

$$\frac{\Gamma\left(D^0 \to \bar{K}^0\eta'\right)}{\Gamma\left(D^0 \to \bar{K}^0\eta\right)} \gg 1.$$

The CLEO result corrected for the difference in phase space,

$$\frac{\Gamma\left(D^0 \to \bar{K}^0\eta'\right)}{\Gamma\left(D^0 \to \bar{K}^0\eta\right)} = 3.1 \pm 0.6,$$

is consistent with this prediction and suggests the importance of W-exchange diagrams.

Table 4: Branching fractions for D^0 decays with $\bar{K}^{*0}$ [%]

	$\bar{K}^{*0}\pi^0$	$\bar{K}^{*0}\eta$	$\bar{K}^{*0}\eta'$
CLEO	$4.6^{+1.1}_{-0.9} \pm 1.1$	$1.7 \pm 0.3 \pm 0.4$	< 0.13(90 % CL)
MARK III	$2.6 \pm 0.3 \pm 0.7$		
Theory:			
WSB w/o FSI	1.4	0.3	0.03
WSB w FSI	3.9	2.5	
1/N,N=∞	2.7		
1/N,N=3	0.25		
QCD sum rules	3.1	0.25	

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