WEAK DECAYS OF LEPTONS AND QUARKS

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1. INTRODUCTION

This report summarizes recent experimental results on the weak decays of leptons and quarks. It will not cover the field of the gauge bosons nor the present experimental evidence for the top quark, as they have been presented in other plenary talks at this conference [1]. In total I have received 35 written contributions and several additional new results have been presented in the parallel sessions. I had to make the usual quite arbitrary choice of which results to present, and would like to apologise for the many omissions.

2. WEAK DECAYS OF LEPTONS

(a) Muons

The LBL-Northwestern-Triumf collaboration, working at Triumf [2] has performed a precision experiment to search for right-handed currents in muon decay by

(i) measuring the momentum spectrum of the positrons from μ^+ decay in the direction opposite to the μ^+-polarization near the end point.

(ii) measuring the amplitude of the spin precession oscillation of the stopped μ^+ in a weak transverse magnetic field.

The positron rate, close to the endpoint as a function of the reduced positron momentum x and the angle θ between μ^+ polarization and positron direction is given by

$$\frac{d^2\Gamma}{dx\, d\cos\theta} \sim 1 - \frac{\delta\xi}{\rho} P\mu \cos\theta$$

with the standard definitions of the muon decay parameters:

parameter	V-A Value	experiment
δ(anisotropic shape)	3/4	0.755±0.009
ξ(asymmetry parameter)	1	0.972±0.014
ρ(isotropic shape)	3/4	0.7517±0.0026

and Pμ the absolute value of the muon polarization. Thanks to the nearly complete polarization of the μ^+ beam derived from π^+ decay at rest near the surface of the production target, the experiment reaches a precision an order of magnitude higher than previous experiments:

$$\frac{\delta\cdot\xi\cdot P\mu}{\rho} = \begin{cases} 0.9989\pm0.0015(\pm0.0018)^* & \text{method (i)} \\ 0.9977\pm0.0019(\pm0.0012) & \text{method (ii)} \end{cases}$$

The measurement can be used to derive the following limits for the (V+A) amplitude

$$|A(V+A)|/|A(V-A)| \le 0.029 \quad (90\%\ CL)$$

For a model in which the V+A contribution is due to a right-handed gauge boson W_R and a right-handed neutrino with less than 10 MeV mass, the value implies a lower limit for the mass of the right-handed gauge boson:

$$M_{W_R} \gtrsim 400\ \text{GeV}\ (470\ \text{GeV}) \quad (90\%\ CL)$$

if arbitrary (in parenthesis zero) mixing angle between left- and right-handed gauge bosons are allowed. This precision measurement can also be used to obtain upper limits on scalar, pseudoscalar and tensor couplings in addition to the standard V-A coupling.

(V-A) + Tensor < 0.027

(V-A) + Scalar + Pseudoscalar < 0.027

We thus conclude that this high precision experiment does not find any evidence of a deviation from the V-A coupling as assumed in the standard model of the electroweak theory.

Two experiments have searched for lepton number violation in μ-decay. The SINDRUM-collaboration working at SIN [3] has stopped $(8.5\pm0.4)10^{12}\mu^+$ and has found zero candidates for the decay mode $\mu^+ \to e^+e^+e^-$ yielding an upper limit of

$$\frac{\Gamma(\mu^+ \to e^+e^+e^-)}{\Gamma(\mu^+ \to e^+\nu\bar{\nu})} < 2.4\cdot10^{-12} \quad (90\%\ CL)$$

* throughout this talk, unless otherwise stated, we quote values as: values ± statistical errors (± systematic errors).

This is an improvement of the previous upper limit from the same group by more than two orders of magnitude.

An experiment using the TPC at Triumf [4] has looked for the decay of μ^- stopped in Ti into e^-Ti, thus searching for lepton number violation. They measure an upper limit of $2 \cdot 10^{-11}$ relative to the μ^- capture rate, which is a factor 3.5 smaller than a previous experiment on the reaction $\mu^- S \rightarrow e^- S$ [5].

From these two experiments we conclude that lepton number conservation – again assumed in the standard model – is valid to a very high degree.

(b) Tau-Lepton

Several new results have been obtained on the τ-lepton. They all confirm its properties as a sequential lepton with universal V-A coupling.

New measurements of the τ-lifetime have been reported by TASSO [6] and Mark II [7]

TASSO : $\tau(\tau) = 3.18^{+0.59}_{-0.75}(\pm 0.56) \cdot 10^{-13}$ sec
Mark II : $\tau(\tau) = 2.86 \pm 0.16(\pm 0.25) \cdot 10^{-13}$ sec

Based on lepton universality we expect a lifetime

$$\tau(\tau) = \tau(\mu) \cdot \left(\frac{m_\mu}{m_\tau}\right)^5 \cdot BR(\tau \rightarrow e\bar{\nu}\nu) = (2.64 \pm 0.14) \cdot 10^{-13} \text{sec}$$

using the $BR(\tau \rightarrow e\nu\bar{\nu}) = 16.5 \pm 0.9\%$ from the particle data tables [8], in agreement with the measurements.

Many new results on the branching ratios of τ-leptons have been presented by CELLO, DELCO, Mark II, and the TPC-experiment [9-13]. Table I shows results on the topological branching ratios and Table II on exclusive branching ratios. There is an impressive agreement between experiment and the model calculation by Tsai [14]. The determination of complicated decay modes with several charged and neutral particles, using the full power of the CELLO electromagnetic calorimeter and the determination of the Cabibbo suppressed decay modes of the τ is a very impressive experimental work.

To conclude, close to 100% of the τ-branching ratios are found in agreement with theoretical expectations based on lepton universality – some of the measurements allow quite sensitive tests: comparing $\Gamma(\tau \rightarrow K\nu_\tau)$ to $\Gamma(K \rightarrow \mu\nu)$ yields an upper limit for the difference in coupling constants g between τ's and μ's to quarks [10]

$$|g_q(g_\tau - g_\mu)| \leq 0.08\ G_F/\sqrt{2} \quad (90\%\ \text{CL})$$

only a factor four bigger than the upper limit on a corresponding difference in μ and e coupling to quarks from the measurement of $\Gamma(\pi \rightarrow e\nu)/\Gamma(\pi \rightarrow \mu\nu)$ [15].

Since the discovery of the τ-lepton, the decay mode $\tau \rightarrow \pi\pi\pi\nu_\tau$ was advertised as the ideal reaction to study the properties of the A1-meson, the $IJ^{PC} = 01^{++}$ non strange meson. Based on 474 events $\tau \rightarrow \pi\pi\pi\nu_\tau$ with an expected background of about 10%, Mark II [11] observes a broad, asymmetric ρπ enhancement around 1100 MeV with spin parity 1^+, with the ρπ system mainly in an s-wave state. Fits to the mass spectrum using various resonance parametrisations and threshold factors, yield mass values in the range 1040±70 to 1160±70 MeV and values for the width between 450 and 550 MeV. These results are compared to the results from diffractive and non-diffractive 3π-production, measured in fixed target experiments with incoming π-mesons where the analysis is complicated by the presence of a large background with the quantum numbers of the A1-meson [16,17].

reference	reaction	mass	width
[11]	$\tau \rightarrow 3\pi\nu_\tau$	1040-1160 MeV	450-550 MeV
[16]	$\pi^- p \rightarrow (3\pi)^- p$	1280±30 MeV	300±30 MeV
[17]	$\pi^- p \rightarrow (3\pi)^0 n$	1240±80 MeV	380±100 MeV

My conclusion is that the question on the parameters of the A1-resonance is certainly not yet settled.

3. WEAK DECAYS OF QUARKS

(a) Strange Quark

I should start by reminding of the beautiful results presented at last year's conferences by the WA2 experiment [18] which measured branching ratios and g_1/f_1 ratio of axial vector and vector form factors for the following hyperon semielectronic decay modes

$\Sigma^- \rightarrow ne^-\nu$, $\Sigma^- \rightarrow \Lambda e^-\nu$, $\Xi^- \rightarrow \Lambda e^-\nu$, $\Xi^- \rightarrow \Sigma^0 e^-\nu$(*),
$\Lambda^- \rightarrow pe^-\nu$

* g_1/f_1 was not measured for this mode.

Different from previous analyses, which had to combine data from various experiments with different systematic errors, the data from this experiment are in perfect agreement with the basic Cabibbo model and allow a precise determination of the Cabibbo angle:

$$\sin\theta_c = 0.231\pm0.003.$$

At this conference first results from the new round of precision experiments on the CP violation in K^o-decays have been presented [19,20]. The experiments measure

$$R = \frac{N(K_L\to\pi^o\pi^o)}{N(K_S\to\pi^o\pi^o)} \Big/ \frac{N(K_L\to\pi^+\pi^-)}{N(K_S\to\pi^+\pi^-)} = 1-6\mathrm{Re}\{\frac{\varepsilon'}{\varepsilon}\}$$

which, together with the measured π-π phase shift values, yield ε'/ε. The experiments find

Chicago-FNAL-Saclay: $\varepsilon'/\varepsilon = -0.0046\pm0.0053\ (\pm0.0024)$
BNL-Yale: $\varepsilon'/\varepsilon = 0.0045\pm0.0080$

The relevance of this value for a test of the standard model will be discussed in section (4) and in more detail in the review talk by Langacker [21]. In the future the experiments expect to decrease the experimental uncertainty by about a factor five, and other experiments are at present set up to measure ε'/ε.

(b) Charm Quark

(i) lifetimes of charmed particles

Many groups are working in this field and most of them have submitted contributions to this conference, in particular

- the NA27 experiment at CERN [22], using the high resolution hydrogen bubble chamber LEBC exposed to a 360 GeV/c π^--beam with a sensitivity of 15.8 events per microbarn has used a sample of 12 background free reconstructed $D^o \to 4$ prong decays yielding a lifetime for the D^o of

  $$\tau(D^o) = (3.5\pm^{1.4}_{0.9})\ 10^{-13}\mathrm{sec}$$

  with very small systematic errors. The same experiment finds from 58 identified D^o's decaying in the charged two particle topology a lifetime:

  $$\tau(D^o) = 5.2\pm^{1.8}_{1.2}\ 10^{-13}\mathrm{sec}$$

  This sample is more affected by background and ambiguities in the interpretation of the decay mode. For the lifetime of the charged D-mesons NA27 finds:

  $$\tau(D^+/D^-) = (9.8\pm^{4.4}_{2.6})\ 10^{-13}\mathrm{sec}.$$

  This result is based on 14 events selected from a sample of sixty observed decays in three and five charged particle topology.

- the BC-75 experiment [23] using the SLAC Hybrid facility exposed to a 20 GeV/c back-scattered laser beam has obtained 19 neutral and 22 charged D-decays, which, added to their previous data yields a sample of 42 neutral, 45 charged and 13 topologically ambiguous charmed meson decays. The resulting lifetimes are

  $$\tau(D^o) = 6.4\pm^{1.1}_{0.9}(\pm0.5)\cdot10^{-13}\mathrm{sec}$$
  $$\tau(D^+/D^-) = 8.2\pm^{1.3}_{1.1}(\pm0.6)\cdot10^{-13}\mathrm{sec}$$

  These results are consistent with the previous experiment from the same group where about half the data sample yielded values:

  $$\tau(D^o) = (6.8\pm^{2.3}_{1.8})\cdot10^{-13}\mathrm{sec}$$
  $$\tau(D^+/D^-) = (7.4\pm^{2.3}_{2.0})\cdot10^{-13}\mathrm{sec}$$

  One of D^o-decays measured is a particularly clean event with a proper lifetime of $55\cdot10^{-13}$ sec ($52\cdot10^{-13}$ sec after correction for the minimum detectable decay length). The decay mode is $K\pi\pi\pi$ with all particles identified by ionization in the chamber or the Cerenkov counter (the K^+ could also be a proton). The $K\pi\pi\pi$ invariant mass is 1869±8 MeV. There is a second vertex in the event, about 1/10 mm from the primary vertex. Possible backgrounds such as an accidental second photon interaction or a secondary $K^op \to K^+\pi^+\pi^-\pi^-p$ interaction can be excluded at the level below one in a thousand for an experiment of the size of BC-73/75.

- the NA11 experiment [24], using an electron trigger and high resolution silicon strip detectors has reconstructed 45 fully contrained D-mesons in the decay modes $K\pi$, $K\pi\pi$ and $K3\pi$ with identified K-mesons, yielding

  $$\tau(D^+) = 11.3\pm^{4.4}_{2.8}(\pm1.8)\cdot10^{-13}\mathrm{sec}$$
  $$\tau(D^o) = 3.6\pm^{0.9}_{0.7}(\pm0.5)\cdot10^{-13}\mathrm{sec}$$

  In addition the group has published three uniquely identified F-mesons with a mass of 1975±4 MeV and an average lifetime of $3.2\cdot10^{-13}$sec [25].

- Based on 27 events from the decay chain $D^{*-} \to D^o(K\pi)\pi^-$ the Mark II experiment has determined [26]

  $$\tau(D^o) = 4.2\pm^{1.3}_{1.0}(\pm1.0)\cdot10^{-13}\mathrm{sec}$$

- The CERN Hyperon experiment has presented last year evidence for the A^+-baryon with the quark content csu at a mass of 2460±25 MeV [27]. Using MWPC's with 0.5 mm wire pitch for the beam and as vertex detectors about 25 cm downstream of the Beryllium target, they are able to measure a mean decay length of the A^+ signal after background subtraction of 4 mm (the measurement precision of the individual events amounts to about 6 mm) and determine:

$$\tau(A^+) = (4.8\pm^{2.9}_{1.8})\cdot 10^{-13}\text{sec}$$

Table III is an attempt to merge the new information on charmed particle lifetimes with previous data and determine averages and errors, in the - probably unjustified hope - that they are closer to the truth than the individual measurements. For the averaging I have used the procedure described in [28] which properly takes into account the fact that for a given number of events the estimated error on the lifetime is proportional to the measured lifetime. For the D-mesons I also took the freedom not to include the the emulsion experiment WA58 into the average, as the 0.6 mm thin emulsion used in this experiment produces a large correction for the effects of the maximum detectable decay length, which makes these data less reliable. For the charged D, I thus obtain a best estimate

$$\tau(D^+/D^-) = (9.1\pm^{1.1}_{0.9})\cdot 10^{-13}\text{sec}$$

with a distribution of the measured values around the mean well compatible with statistics.

The same procedure for the neutral D's yields a value of

$$\tau(D^o) = (4.29\pm^{0.42}_{0.40})\cdot 10^{-13}\text{sec}$$

The results from the BC73/75 experiment have the biggest deviation from above mean value. Excluding this result - for which I have no good reason as I was not able to find a systematic effect which produces a particularly long D^o lifetime - changes the mean by $-4\cdot 10^{-13}$sec. It is worth noting that the clean longlived $D^o \to K\pi\pi\pi$ decay discussed above has a probability of $\sim 2.5\cdot 10^{-4}$ to occur in a sample of 45 decays if the lifetime is $4.29\cdot 10^{-13}$sec, compared to 1.3% for the lifetime quoted in the BC73/75 experiment.

This discussion should make it clear that the question of the D^o lifetime may not yet be completely settled. The values for $\tau(D^o)$ and $\tau(D^+)$ in the tables result in

$$\tau(D^+)/\tau(D^o) = 2.1\pm 0.2$$

a value significantly different from one and compatible with the ratio of semileptonic branching ratios presented by the Mark III group at this conference:

$$\frac{BR(D^+ \to e\ X)}{BR(D^o \to e\ X)} = 2.78\pm 0.76\pm^{0.31}_{0.42}$$

Much less is known about the lifetimes of the other charmed particles. Contributions from CLEO, ARGUS, TASSO, HRS and NA11 confirm the mass of the F-meson at 1970 MeV [29]. It is now also realized that the background from other charm decays to the F-meson is very complicated and good particle identification is absolutely necessary to resolve the D-F-Λ_c ambiguities. As a result most experiments have retracted their earlier results and at present the most convincing results come from the NA11 collaboration with

$$\tau(F) = (3.2\pm^{3.0}_{1.3})\cdot 10^{-13}\text{sec}$$

based on three uniquely identified $KK\pi$ decays.

As described above, there is only one experiment which has determined the lifetime of the A^+-charmed hyperon

$$\tau(A^+) = (4.8\pm^{2.9}_{1.8})\cdot 10^{-13}\text{sec}.$$

No new results have been presented on the Λ_c lifetime so that we just quote the values given at the Paris conference [30] of

$$\tau(\Lambda_c) = (2.2\pm^{0.9}_{0.5})\cdot 10^{-13}\text{sec}.$$

with a warning that the errors seem very small given the limited data sample and the systematic difficulties of the experiments.

(ii) <u>branching ratios of charmed particles</u>

The major contribution for the branching ratios of the D-mesons to this conference comes from the Mark III detector at SPEAR [31]. This experiment has collected 8100 events per nb at the peak of the $\psi''(3770)$, corresponding to 24,000 D^+D^- pairs and 30,000 $D^o\bar{D}^o$ pairs produced. The detector allows tracking of charged particles (spatial resolution 240 μm and momentum resolution $\delta p/p = \sqrt{(0.0015p[\text{GeV}])^2+(0.0015)^2)}$ over 94% of 4π, particle identification via time-of-flight (180 psec resolution, K/π separation up to 1 GeV) and energy loss of charged particles (17% resolution), and measurement of electromagnetic showers with a resolution of

$$\frac{\Delta E}{E} = 0.18/\sqrt{E[\text{GeV}]}$$

The apparatus achieves a hadron to electron rejection of 4%. To illustrate the quality of the data Fig. 1 shows the effective mass spectrum for various Cabibbo favoured decay channels of D^+ and D^o decays.

Clean signals are observed, even in channels with several neutral particles allowing a precise determination of the product of production cross-section times branching ratio, yielding relative branching ratios with small errors. To obtain absolute branching ratios one can either use the absolute production cross-sections of the neutral and charged D-mesons from previous experiments (Table IV), or use events with both D-mesons reconstructed in exclusive decay channels (doubly tagged events). This method yields values of the branching ratios which contain no assumptions about the production and have errors dominated solely by statistics and small uncertainties in the reconstruction efficiency. Table V compares the results for the $D \to K\pi$ and $D \to K\pi\pi$ branching ratios from the various methods and the value quoted in the particle data booklet. One notices a factor two difference, well outside the errors quoted - a result of averaging experiments not taking into account common systematic errors.

The same method of tagged decays has been used to determine the semileptonic branching ratios. From a sample of 2673±59 D^o and 1331±41 D^+/D^- events the following branching ratios are found.

$$BR(D^o \to e^+X) = 0.06 \pm 0.02(\pm 0.02)$$

$$BR(D^+ \to e^+X) = 0.17 \pm 0.03(\pm 0.03)$$

$$\frac{BR(D^+ \to e^+X)}{BR(D^o \to e^+X)} = 2.78 \pm 0.76(\pm^{0.31}_{0.41})$$

Because the decays are $\Delta I=0$, the partial semileptonic width of the D^o and D^+ are expected to be practically identical, so this ratio gives the ratio of lifetimes as discussed in the previous section.

This experiment also managed to make precise measurements on several Cabibbo suppressed modes. The quality of the data is best illustrated by the $K^-\pi^+$, K^-K^+ and $\pi^-\pi^+$ mass spectra of Fig. 2. Clean signals are seen in the rare decay channels and feedthrough from the $K\pi$ channel with its factor ten higher branching ratio, is at a tolerable level. The measured branching ratios are given in Table IV.

Besides the Mark III only a few results on branching ratios have been presented like

$$BR(D^o \to K^+\pi^+\pi^-\pi^-) = (7.1 \pm 2.5)\%$$

$$BR(D^o \to eX) = (7 \pm^{6}_{4})\%$$

from the NA27 experiment [22] and the ratio

$$\frac{BR(D^o \to K\pi\pi\pi)}{BR(D^o \to K\pi)} = 2.17 \pm 0.28(\pm 0.22)$$

from ARGUS [33].

Before discussing the branching ratio of other charmed particles, we would shortly discuss the phenomenological implication of the results on D-meson lifetimes and branching ratios.

As is now known since quite some time, the most simple version of the spectator model of heavy flavour decay is clearly ruled out from the difference of charged and neutral D-meson lifetimes and the difference in semileptonic branching ratios. Corrections due to the effect of finite quark masses, QCD and the antisymmetrization of amplitudes for topologies with identical quarks in the final state, yield - within quite big uncertainties - to the following predictions [34]

$$\tau(D^+) > \tau(D^o) \approx \tau(F^+)$$

$$BR(D^o \to \ell X) = (13\text{-}17)\%$$

$$BR(D^+ \to \ell X) = (14\text{-}20)\%$$

Although the corrections reduce the disagreement between data and spectator model prediction, the measured rate $BR(D^o \to \ell X) = 6 \pm 2(\pm 2)\%$ is in clear disagreement. The charged D however is in agreement with the prediction, in particular if one considers that the mass difference between charmed and strange quarks of 1.1-1.35 GeV, which can be estimated from the lepton momentum spectrum in the semileptonic decays, gives a reasonable estimate of the absolute lifetime of the charged D-mesons.

Several ideas have been brought forward to phenomenologically explain D-meson decays. The inclusion of W-exchange and annihilation diagrams (Fig. 3), originally not included as they are strongly suppressed at the quark diagram level by the V-A coupling of quarks to the W-gauge boson, leads to several predictions:

(i) - existence of decay modes like $D^o \to K^o\overline{K}^o$, $K^o\phi$ which are unique signatures for this diagram; the experimental limit of $BR(D^o \to K^o\phi)/BR(D^o \to K^-\pi^+) \lesssim 1.7\%$ is however not yet stringent enough.

- the qualitative (simplified) picture as presented in Table VI.

The data follow the trend of the prediction, but a more detailed quantitative comparison should be made. Finally only good measurements on the F-meson properties will show if the above picture is consistent.

The information on decay properties of the F-mesons presented at this conference is quite limited. The product of cross-section times $F \to \phi\pi$ branching ratio normalized to the $\mu\mu$ cross-section in e^+e^- has been measured [32,35,36]:

CLEO 2.0±0.5%

ARGUS 1.7±0.5(±0.5)%

TASSO 6.4±1.3(±1.9)%

Assuming that of the order of 1/7 of the charm cross-section is due to F's yields a branching ratio of the order of 4%. ARGUS has in addition determined [32]:

$$\frac{BR(F \to \phi 3\pi)}{BR(F \to \phi\pi)} = 2.7 \pm 1.1$$

No new significant information has been presented on decay branching of the other stable charmed particles.

(c) Beauty Quark

(i) lifetime

Four experiments (DELCO, JADE, MAC and TASSO) [37-40] have presented new results at this conference, Mark II [41] has presented new data at the SLAC summer school at the beginning of August. None of the experiments identifies exclusive decay channels and thus the lifetime measured, is the lifetime of an unknown mixture of B-hadrons, probably different in the different experiments due to selection criteria.

All experiments determine the lifetime from the measurement of the projected impact parameter - the minimum distance of a track from the estimated position of the interaction vertex. Table VII tries to summarize some of the essential numbers for the different experiments. The main differences are:

- the spatial resolution on the extrapolated tracks, which is however washed out by the finite size of the beam, the center of which is taken as the interaction vertex.
- the cleanliness and statistics in the b-enriched and c-enriched samples.

TASSO is the only group, which does not select leptons from the heavy flavour decay to tag beauty and charm events. They obtain a beauty and charmed enriched data sample by cutting on the product of sphericities $s_1 \cdot s_2$, defined as the sphericities in the individual hemispheres after a Lorentz boost along the sphericity axis of the event with a γ-factor of 1.4. This method profits from the much larger charged decay multiplicity from beauty decay compared to charm decay. The method has the advantage that many more tracks from heavy flavour decay can be used. It needs however very extensive Monte Carlo calculations, which include a detailed knowledge of the inclusive decay properties of all quarks, their production and fragmentation properties and of course the performance of the apparatus.

As can be seen from the table all experiments find lifetimes of the order of one to two picoseconds significantly different from zero, thus confirming last year's results [42]. Given the systematic difficulties of these experiments, the agreement between the experiments is impressive - I nevertheless find it too early to quote an average value with error bars but prefer to give only the above quoted range of one to two picoseconds. It would be clearly comforting to see a few events in which beauty decay vertices are measured with an error significantly smaller than the decay path.

(ii) inclusive branching ratios

New data on charged multiplicities and particle yields from beauty decay have been reported by CLEO [43] - they are shown in Table VIII. The rates are as expected from dominance of the beauty to charm transition. No clean ψ-signal from B-decay has been found so far, and an upper limit of 1.6% at 90% confidence level has been determined, well compatible with the ideas on colour suppression.

Many groups have measured the semileptonic branching fractions. All the results are compatible and yield the average value [44,45]

$BR(B \to eX) = (11.3 \pm 0.9)\%$

$BR(B \to \mu X) = (12.0 \pm 1.0)\%$

within the expected range of the spectator model prediction for B-decay - the corresponding number in the charm sector as measured at the e^+e^- storage rings is (8.4±0.6)%.

In principle, if the production rate of B^o and B^+ is known, it is possible to obtain the relative leptonic branching ratios

$$\frac{BR(B^o \to \ell X)}{BR(B^+ \to \ell X)}$$

from comparing single and double lepton rates from B-decay. The method is however not very sensitive and at present only yields the range 0.25 to 2.9 [46].

Both CLEO [45] and CUSB [47,48] have measured the momentum spectrum of leptons in semileptonic B-decay. The shape of the spectrum at high momenta is very sensitive to the maximum hadronic recoil mass and allows the determination of the ratio of transition rates $\frac{\Gamma(B \to \ell\nu u)}{\Gamma(B \to \ell\nu c)}$.
Both groups find upper limits of about 0.045. CLEO also measures upper limits of the exclusive decay modes

$$B^{o} \to \pi^{+}\pi^{-} \quad < 0.05\% \text{ at } 90\% \text{ CL}$$

$$B^{+} \to \rho^{o}\pi^{+} \quad < 0.06\% \text{ at } 90\% \text{ CL}$$

which give similar, but model-dependent limits on the above ratio of transition rates.

CLEO [46] has given a new upper limit for the ratio of B-branching ratios

$$\frac{BR(B \to \mu^{+}\mu^{-}X)}{BR(B \to \mu X)} < 2.7\% \text{ at } 90\% \text{ CL}$$

thus excluding models in which the b-quark is a singlet decaying via virtual Z^{o} emission.

(iii) exclusive branching ratios

CLEO [43] reports on three more exclusive B-decays and a new method of determining the exclusive channel $B^{o} \to D^{*+}\pi^{-}$ in a semi-inclusive way. The results are:

$$BR(B^{o} \to D^{*+}\pi^{-}) = (2.6\pm1.9)\%$$

$$BR(B^{o} \to D^{o}\pi^{+}\pi^{-}) = (13\pm9)\%$$

$$BR(B^{-} \to D^{*+}\pi^{-}\pi) = (4.8\pm3)\%$$

$$BR(B^{-} \to D^{o}\pi^{-}) = (4.2\pm4.2)\%$$

In view of the new values for the $D^{o} \to K\pi$ branching ratios measured by Mark III (see section 3b), the above B^{o} branching ratios have to be increased by about a factor 2.

(iv) conclusions on B-decays

- There are now five experiments which all agree that the lifetime of B-hadrons is about one to two picoseconds.
- So far all measurements on B's are in agreement with the standard model and the dominance of spectator decays for the B's - the present quality of the data however does not provide a stringent test.
- The measurement on B-hadrons has provided a powerful tool in determining important parameters of the standard model, as will be discussed in the next section.

4. CONCLUSIONS

In the final section, I would like to point out my main physics conclusions which have emerged from the experimental study of the weak decays of leptons and quarks during recent years.

First of all, the standard model of electroweak and strong interactions with three families of quarks and leptons is exceedingly successful. As discussed in the talk, new experiments have confirmed lepton-number conservation, the universality of the lepton coupling, together with the V-A structure, with very high precision. The couplings between the quarks are well described by a 3X3 mass-mixing matrix and within this model the absolute values of all the matrix elements have now been determined with quite good precision (see Table IX). In particular, the improved measurements of the lifetime of beauty hadrons and the precise upper limit for the ratio of the transition $b \to u$ relative to $b \to c$ has resulted in a precise determination of the elements $|U_{ub}|$ and $|U_{cb}|$. The coupling between the i and j'th generation of quarks follows the pattern

$$|U_{13}| \ll |U_{23}| \ll |U_{12}|$$

From this trend one may expect that either a fourth generation of quarks does not exist, or that it is nearly completely decoupled from the lower lying generations. During this conference there was a lot of discussion as to whether the present values of the mass-mixing matrix, a top mass around or in excess of 40 GeV and a value for the CP-violation parameters $\epsilon'/\epsilon < 0.02$, as indicated by the recent measurement, already exclude the validity of the standard model. My conclusions from the discussions in the parallel session was that the calculations are sufficiently uncertain that this is not the case - but the talk of Langacker will cover this topic in more detail.

As far as the complicated interplay between weak and strong interactions in the hadronic weak decays of quarks is concerned, the situation is more complicated than originally hoped. Experimentally the lifetime difference of neutral and charged

D-mesons is well established and a large variety of D-meson branching ratios have been measured. In the near future several phenomenological analyses are expected, comparing the new data to the models and determining their parameters. Probably several models will be found to be compatible and lifetime and branching ratio measurements of the F-meson will decide which model is the correct one.

Finally, we expect to learn a lot from the decay of B-hadrons - but seeing the big experimental difficulties, this may not be in the very near future.

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REFERENCES

[1] R. Böck and J. Rohlf, UA1 results, plenary talks this conference
J.P. Reppelin, UA2 results, plenary talk this conference.

[2] B. Balke et al., Search for right-handed currents in muon decay, paper 37 submitted to this conference.

[3] W. Bertl et al., A search for the decay $\mu^+ \to e^+e^+e^-$, paper 104 submitted to this conference.

[4] Private communication by C.K. Hargrove, Natl. Research Council of Canada on the Triumf-TPC experiment, this conference.

[5] Badertsch et al.,Lett. Nuovo Cimento 28 (1980) 401.

[6] M. Althoff et al. (TASSO collaboration), Determination of the τ-lifetime in high energy e^+e^- annihilation, paper 276 submitted to this conference and DESY 84-017 (Feb. 1984).

[7] G.S. Abrams et al. (Mark II collaboration), Precision measurement of the τ-lifetime, paper 870 submitted to this conference.

[8] Particle Properties, Data booklet, April '84 edition.

[9] H.J. Behrend et al. (CELLO collaboration), New data on semihadronic decays of the τ-lepton, paper 456 submitted to this conference and DESY 84-008 (Jan. 1984).

[10] G.B. Mills et al. (DELCO collaboration), Measurement of the Cabibbo suppressed decays $\tau \to K\nu_\tau$ and $\tau \to K\nu_\tau + n\pi^0$, paper 562 submitted to this conference and CALT-68-1104.

[11] G.S. Abrams et al. (Mark II collaboration), The $\tau \to 3\pi\nu_\tau$ decay process, paper 878 submitted to this conference.

[12] H. Aihara et al. (PEP4-TPC collaboration), Tau Lepton branching fractions, paper 363 submitted to this conference.

[13] R. Brandelik et al., Phys. Lett. 117B (1982) 365.

[14] Y.S. Tsai, Phys. Rev. D4 (1971) 2821.

[15] J. Heintze et al., Phys. Lett. 60B (1976) 302.

[16] C. Daum et al., Phys. Lett. 89B (1980) 281.

[17] J.A. Dankowych et al., Phys. Rev. Lett. 46 (1981) 580.

[18] M. Bourquin et al., Z. Phys. C 21 (1983) 27 and references therein.

[19] P. Peyaud et al., A measurement of ε'/ε in the K^0-system at Fermilab, paper 814 submitted to this conference.

[20] BNL-Yale collaboration, presentation at this conference.

[21] P. Langacker, Status of electroweak theory, plenary talk this conference.

[22] J. Hrubec et al. (EHS collaboration), Charm particle production and decay properties observed in 360 GeV/c π^-p interactions, paper 933 submitted to this conference, and
M. Aguilar-Benitez, Neutral D-meson properties in 360 GeV/c π^-p interactions, CERN-EP/84-73, accepted by Physics Letters B.

[23] K. Abe et al. (SLAC Hybrid Facility Photon Collaboration), Charm photoproduction at 20 GeV including preliminary lifetime results with improved optical resolution, paper 296 submitted to this conference; and
K. Abe et al., Phys. Rev. D30 (1984) 1.

[24] R. Bailey et al. (ACCMOR collaboration), Measurement of the the lifetime of charged and neutral D-mesons with high resolution silicon strip detectors, paper 361 submitted to this conference.

[25] R. Bailey et al. Phys. Lett. 139B (1984) 320.

[26] G.S. Abrams (Mark II collaboration), A measurement of the D^0-lifetime, paper 872 submitted to this conference.

[27] S.F. Biagi et al., Phys. Lett. 122B (1984) 455 and Measurement of the lifetime of the charmed strange baryon A^1, paper 584 submitted to this conference.

[28] R. Sidwell et al., Ann. Rev. Nucl. and Particle Sci. 33 (1983) 539.

[29] A. Silverman, Heavy quark scattering and search for new particles, plenary talk this conference.

[30] G. Kalmus, Weak decays of new particles, plenary talk at the XXI conference on high energy physics, Paris 1982.

[31] R.M. Baltrusaitis et al. (Mark II collaborion), The properties of charmed D-mesons measured in e^+e^- collisions at $\sqrt{s}$ = 3768 MeV, paper 344 submitted to this conference.

[32] H. Albrecht et al. (ARGUS collaboration), Production and decay of the F-meson in e^+e^- ammihilation at 10 GeV centre-of-mass energy, paper 672 submitted to this conference.

[33] H. Albrecht et al. (ARGUS collaboration), Production and decay of charged D^* meson in e^+e^- annihilation at 10 GeV centre-of-mass energy, paper 673 submitted to this conference.

[34] R. Rückl, Weak decays of heavy flavours, Habilitationsschrift Universität München Oct.1983, and to appear as Physics Reports and private communication R. Rückl this conference.

[35] A. Chen et al., Phys. Rev. Lett. 51 (1983) 634.

[36] M. Altoff et al., Phys. Lett. 136B (1984) 130.

[37] B. Barish et al. (DELCO collaboration), Measurement of lifetime of B-hadrons, paper presented at this conference.

[38] W. Bartel et al. (JADE collaboration), Determination of the B-lifetime, paper submitted to this conference.

[39] E. Fernandez et al. (MAC collaboration), A measurement of the B-lifetime, paper 863 presented at this conference.

[40] M. Althoff et al. (TASSO collaboration), Determination of the average lifetime of Bottom Hadrons, paper presented at this conference.

[41] J.A. Jaros (MARK II collaboration), Measurement of lifetimes of shortlived particles, talk presented at the 1984 SLAC summer school.

[42] E. Fernandez et al., Phys. Rev. Lett. 51 (1983) 1022.
N.S. Lockyer et al., Phys. Rev. Lett. 51 (1983) 1316.

[43] CLEO collaboration, Observation of two-body decays of B-mesons, paper 467 submitted to this conference.

[44] M. Althoff et al. (TASSO collaboration), Production and muonic decay of heavy quarks in e^+e^- annihilation at 34.5 GeV, paper 271 submitted to this conference and DESY 83-121 (Nov. 1983).
M. Althoff et al. (TASSO collaboration), Inclusive electron production from heavy quarks, paper 296 submitted to this conference.
PEP4-TPC collaboration, Prompt muon production in e^+e^- annihilations at 29 GeV, paper 563 submitted to this conference.
PEP4-TPC collaboration, Prompt electron production in e^+e^- annihilations at 29 GeV, paper 564 submitted to this conference.
G. Levman et al. (CUSB collaboration), A measurement of the semileptonic decay of B-mesons into muons, paper 652 submitted to this conference.

[45] A. Chen et al. (CLEO collaboration), Limit on the b → u coupling from semileptonic B decay, CLNS-84/597 and CLEO-84-1 (Feb. 1984).

[46] A. Chen et al. (CLEO collaboration), Upper limit on flavour changing and neutral current decays of the b quark, CLNS-84/612 and CLEO-84-6 (May 1984).

[47] C. Klopfenstein et al. (CUSB collaboration) Phys. Lett. 130B (1983) 444.

[48] J. Lee-Franzini, A new determination of the mixing angles, paper 655 submitted to this conference.

Table captions

Table I — Topological branching ratios of the τ-lepton.

Table II — Exclusive branching ratios of the τ-lepton.

Table III — (a) Measurements of lifetime of charged D-mesons.
(b) Measurements of lifetime of neutral D-mesons.

Table IV — Branching ratios of D-mesons, assuming $\sigma(D^o)$ = 7.5±1.1(±1.2)nb; $\sigma(D^+/D^-)$ = 6.0±0.9(±1.0)nb [31].

Table V — Comparison of various methods to determine branching ratios of D-mesons.

Table VI — Phenomenological predictions for D-decays [34].

Table VII — Measurement of B-lifetime.

Table VIII — Inclusive properties of B-meson decays.
(a) charged multiplicity
(b) decay products.

Table IX — Absolute values of mass-mixing matrix.

Figure captions

Fig. 1 — Mass spectra of Cabibbo allowed D-decay modes from the Mark III experiment.

Fig. 2 — Kπ, KK and ππ mass spectra from D^o-decays (Mark III experiment).

Fig. 3 — Phenomenological quark diagrams for charm decays.
Q denotes the heavy quark, W the exchanged gauge boson.

Table I: Topological branching ratios of the τ-lepton

topology	TASSO [12]	CELLO [9]	PEP4-TPC [13]
1 charged	0.847±0.011(±0.015)	0.852±0.026(±0.013)	0.852±0.009(±0.015)
3 charged	0.153±0.011(±0.015)	0.148±0.020(±0.013)	0.148±0.009(±0.015)
5 charged	< 0.007	< 0.01	< 0.007

Table II: Exclusive branching ratios of the τ-lepton

decay mode	group	BR	expected [14]
$\tau \to e\nu_e\nu_\tau$	CELLO	18.3±2.4±1.9%	18.3%
$\to \mu\nu_\mu\nu_\tau$	"	17.6±2.6±2.1%	17.9%
$\to \rho\nu_\tau$	"	22.1±1.9±1.6%	22.3%
$\to \pi\pi^o\nu_\tau \neq$ res	"	0.3±0.1±0.1%	
$\to \pi\pi\pi\pi^o\nu_\tau$	"	6.2±2.3±1.7%	6.6%
$\to \pi\pi^o\pi^o\pi^o\nu_\tau$	"	3.0±2.2±1.5%	1.1%
$\to \pi\nu_\tau$	"	9.9±1.7±1.3%	10.8%
$\to \pi\pi\pi\nu_\tau$	"	9.7±2.0±1.3%	18.7%
$\to \pi\pi^o\pi^o\nu_\tau$	"	6.0±3.0±1.8%	18.7%
$\to \pi\pi\pi\pi\pi\nu_\tau$	"	< 0.5%	0.9%
$\to K\nu_\tau$	DELCO	0.59±0.18%	0.5%
$\to K^*\nu_\tau$	Mark II	1.7 ± 0.7%	1.05%
$\to K\nu_\tau n\pi^o$	DELCO	1.7 ± 0.3%	1.3%
Sum		94 ± 8%	98.5%

Table III:

(a) Measurements of lifetime of charged D-mesons

Experiment	$\tau(10^{13}$ sec$)$	Events
E-531	$11.5^{+7.5}_{-3.5}$	11
WA-58	$3.4^{+2.0}_{-1.0}(\pm0.7)$	11
NA-11	$11.3^{+4.4}_{-2.8}(\pm1.8)$	20
NA-16	$8.4^{+3.5}_{-2.2}$	15
NA-18	$6.3^{+4.8}_{-2.2}(\pm0.5)$	9
NA-1	$9.5^{+3.1}_{-1.9}$	98
NA-27	$9.8^{+4.4}_{-2.6}$	14
BC73/75	$8.2^{+1.3}_{-1.1}(\pm0.6)$	45
average excl. WA58 $9.1^{+1.1}_{-0.9}$		

(b) Measurements of lifetime of neutral D-mesons

Experiment	$\tau(10^{13}$ sec$)$	Events
E-531	$3.3^{+0.5}_{-0.4}(\pm0.25)$	57
WA-58	$2.3^{+1.4}_{-0.7}$	22
NA-16	$4.1^{+1.3}_{-0.9}$	16
NA-18	$4.1^{+2.6}_{-1.3}$	8
NA-11	$3.6^{+0.9}_{-0.7}(\pm0.5)$	25
NA-27	$3.5^{+1.4}_{-0.9}$	12
BC73/75	$6.4^{+1.1}_{-0.9}(\pm0.5)$	42
Mark II	$4.2^{+1.3}_{-1.0}(\pm1.0)$	27
average excl. WA58 $4.29^{+0.42}_{-0.40}$		

Table IV: Branching ratios of D-mesons, assuming
$\sigma(D^o) = 7.5\pm1.1(\pm1.2)$nb; $\sigma(D^+/D^-) = 6.0\pm0.9(\pm1.0)$nb [31].

D^o decay mode	branching ratio
$K^-\pi^+$	3.7 ±0.6 (±0.7)%
$\bar{K}^o\pi^+\pi^-$	5.3 ±0.9 (±0.9)%
$K^-\pi^+\pi^o$	7.1 ±1.2 (±1.7)%
$K^-\pi^+\pi^+\pi^-$	7.5 ±1.2 (±1.4)%
$K^o\pi^+\pi^-\pi^o$	10.2 ±2.6 (±2.3)%
$\bar{K}^o\pi^o$	1.3 ±0.3 (±0.3)%
$\bar{K}^oK^+K^-$	1.1 ±0.4 (±0.4)%
K^+K^-	0.46±0.10(±0.10)%
$\pi^+\pi^-$	0.14±0.05(±0.05)%

D^+/D^- decay mode	branching ratio
$K^o\pi^+$	2.5 ±0.5 (±0.4)%
$K^-\pi^+\pi^+$	7.0 ±1.1 (±1.3)%
$\bar{K}^o\pi^+\pi^o$	7.6 ±1.6 (±1.8)%
$\bar{K}^o\pi^+\pi^+\pi^-$	6.3 ±1.3 (±1.2)%
$K^+K^-\pi^+$	0.50±0.18(±0.15)%
$\phi\pi^o$	0.58±0.18(±0.14)%
$\pi^+\pi^+\pi^-$	0.41±0.13(±0.11)%

Table V: Comparison of various methods to determine branching ratios of D-mesons.

	Mark III doubly tagged	Mark III using $\sigma(D)$	Mark II using $\sigma(D)$	Particle Data average ('83)
$D^o \to K^-\pi^+$	4.9±0.9(±0.5)%	3.7±0.6(±0.7)%	3.0±0.6%	2.4±0.4%
$D^+ \to K^-\pi^+\pi^+$	9.1±1.5(±0.9)%	7.0±1.1(±1.3)%	6.3±1.5%	4.6±1.1%

Table VI Phenomenological predictions for D-decays [34]

prediction	experiment
$\tau(D^+) > \tau(D^o) \sim \tau(F^+)$	OK for D's
$\Gamma(D^+ \to \ell X) = \Gamma(D^o \to \ell X) < \Gamma(F^+ \to \ell X)$	OK for D's
D^o: $\frac{\text{BR(Cabibbo forbidden)}}{\text{BR(Cabibbo allowed)}} \sim 2\tan^2\theta_c$	$\frac{\langle BR(\pi\pi/KK)\rangle}{BR(K\pi)} \sim 8\%$
D^+: $\frac{\text{BR(Cabibbo forbidden)}}{\text{BR(Cabibbo allowed)}} \sim \frac{2\tau(D^+)}{\tau(D^o)}\tan^2\theta_c$	$\frac{BR(\bar{K}^oK^+)}{BR(\bar{K}^o\pi^+)} \sim 30\%$
F^+: $\frac{\text{BR(Cabibbo forbidden)}}{\text{BR(Cabibbo allowed)}} \sim \tan^2\theta_c$	no information

Table VII Measurement of B-lifetime

	DELCO	MAC	MarkII	JADE	TASSO*
Luminosity[pb^{-1}]	118	160	220	63	78.7 (13.7)
resolution including beam spread [μm]	400	600	200	570	380 (1100)
b-enrichment cuts	$p(\ell)>1GeV$ $p_T(\ell)>1GeV$	$p(\ell)>2GeV$ $p_T(\ell)>2GeV$	$p(\ell)>2GeV$ $p_T(\ell)>2GeV$	$p(\ell)>1.5GeV$ $p_T(\ell>0.9GeV$	$p>1GeV$ $S1 \cdot S2>0.1$
# tracks					
electrons	60	160	150	25	
muons	-	238	120	74	
hadrons	-	-	-	-	716 (7526)
fraction of tracks from b-decay	0.77	0.53	0.62	0.65	0.32
mean impact p. from b-sample [μm]	215±81	159±39 83±42	80±17	282±66 457±114	105±17 109±23
lifetime in psec	$1.16\pm^{.37}_{.34}\pm.23$	$1.6\pm.4\pm.4$	$.85\pm.17\pm.21$	$1.8\pm^{.5}_{.3}\pm.4$	$1.83\pm^{.38}_{.37}\pm^{.37}_{.34}$

* Values with/without parentheses give results with/without the TASSO vertex chamber

Table VIII: Inclusive properties of B-meson decays

(a) charged multiplicity

mode	multiplicity
average	5.5±0.03(±0.15)
hadronic	6.0±0.3
semileptonic	3.8±0.4

(b) decay products

particle	multiplicity
$B \to K^+/K^-$	0.97±0.12(±0.20)
$B \to K^0/\bar{K}^0$	0.72±0.12(±0.14)
$B \to p$	0.03
$B \to \Lambda^0$	0.03
$B \to J/\psi$	0.01±0.005
$B \to D^0$	0.8±0.2(±0.2)

Table IX: Absolute values of mass-mixing matrix elements

$\lvert U_{ij} \rvert$	d	s	b
u	0.9737±0.0025	0.231±0.003	< 0.005
c	0.231±0.003	0.972±0.002	0.044±0.005
t	< 0.015	0.043±0.0001	> 0.999

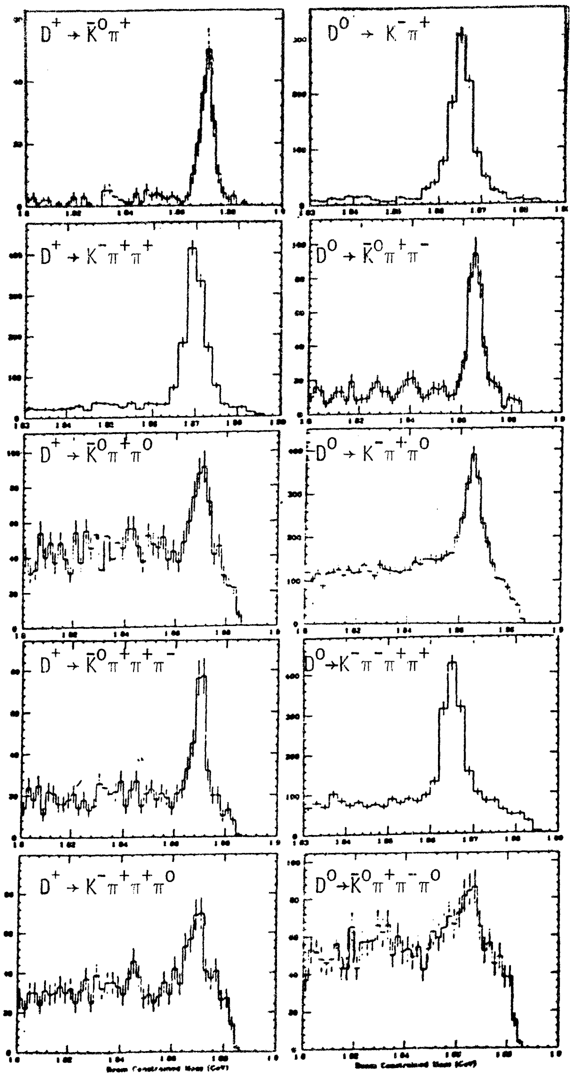

Fig. 1

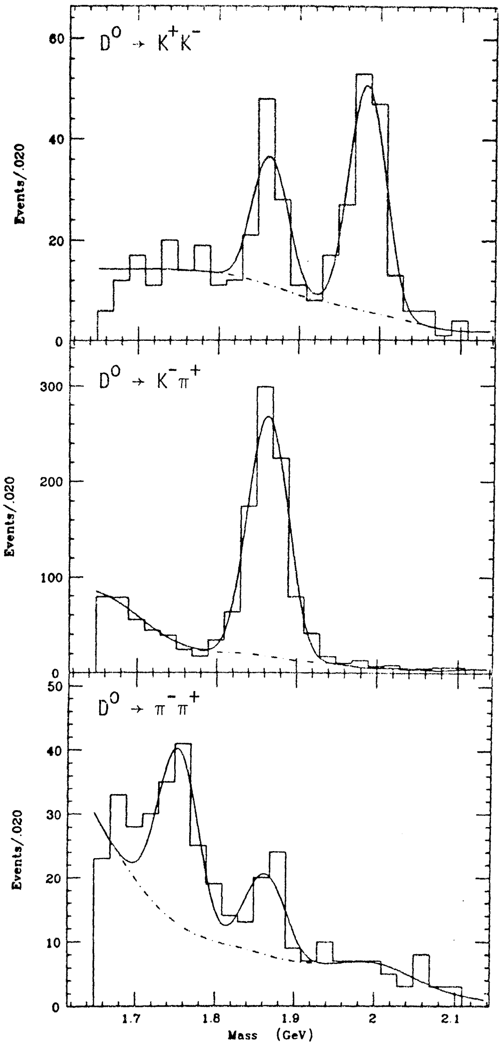

Fig. 2

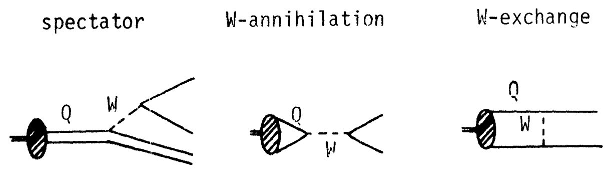

Fig. 3