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TAU DECAYS AND CVC

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НОВОСИБИРСК

TAU Decays and CVC

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ABSTRACT

An update of the calculation of the branching ratios for the τ-lepton hadronic decays is presented based on the hypothesis of conserved vector current (CVC) and experimental data on e^+e^- annihilation into hadrons. CVC based predictions seem to be consistent with the experimental information on τ-lepton decays.

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1 Introduction

The hypothesis of the conserved vector current (CVC) and isospin rotation relate to each other $e^+e^- \to$ hadrons and hadronic decays of τ where in both cases hadrons are in the isovector state [1].

For the vector part of the weak hadronic current the distribution over the mass of produced hadrons is

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 \cos^2\theta_c S_{EW}}{32\pi^2 m_\tau^3}(m_\tau^2 - q^2)^2(m_\tau^2 + 2q^2)v_1(q^2)$$

where a spectral function

$$v_1(q^2) = \frac{q^2\sigma^{I=1}_{e^+e^-}(q^2)}{4\pi\alpha^2},$$

θ is the Cabibbo angle and S_{EW} is a radiative correction equal to 1.0194 according to [2].

The allowed quantum numbers for the hadronic decay channels are:

$$J^{PG} = 1^{-+}, \quad \tau \to 2n\pi\nu_\tau, \quad \omega\pi\nu_\tau, \quad \eta\pi\pi\nu_\tau, \cdots$$

After integration

$$\frac{B(\tau^- \to X^-\nu_\tau)}{B(\tau^- \to e^-\nu_e\nu_\tau)} = \frac{3\cos^2\theta_c S_{EW}}{2\pi\alpha^2 m_\tau^8}$$

$$\times \int_{4m_\pi^2}^{m_\tau^2} dq^2 q^2 (m_\tau^2 - q^2)^2 (m_\tau^2 + 2q^2)\sigma^{I=1}_{e^+e^-}(q^2).$$

Theoretical predictions for the branching ratios of different τ decay modes based on CVC were given by many authors [3–11] and generally showed agreement with the experimental data. New comparison of CVC and experiments was motivated by recent progress of experiments on τ decays as well as by updated information from e^+e^- annihilation into hadrons, coming mostly from the DM2 experiment at Orsay. Most of the e^+e^- information at low energy ($\sqrt{s} < 1.4$ GeV) comes from VEPP-2M at Novosibirsk, while at higher energy data from DCI at Orsay and ADONE at Frascati were used.

As in our previous work [9], to calculate the integral we prefer to use the direct integration over the experimental values of cross sections. In this approach one can take into account uncertainties of separate measurements in a straightforward manner. The alternative method which was used in most of the previous works is to make a fit of the experimental points within some model and integrate the arising parametrization of the data. This procedure inevitably leads to a model dependence and it is not clear how experimental errors, especially systematic uncertainties, can be taken into account.

Results of the calculation will be usually presented for the ratio of the branching of some specific hadronic mode to the leptonic one (R_l) and/or the absolute branching ratio of the hadronic mode. For the latter we will use the value of $B(\tau \to e\nu_e\nu_\tau) = (18.01 \pm 0.18)\%$ recommended by Review of Particle Properties (RPP-94) [12].

2 $\tau^- \to \pi^-\pi^0\nu_\tau$

The reaction $e^+e^- \to \pi^+\pi^-$ was studied with high precision at low energy by two groups OLYA and CMD which found good agreement between each other and published the results of the joint analysis in [13]. CMD studied 24 points from 360 to 820 MeV with a systematic uncertainty less than 2%, whereas OLYA scanned the energy region from 640 to 1400 MeV with a small energy step and had a systematic uncertainty from about 4% at the ρ-meson peak up to 15% at 1400 MeV. Also used were the older data near

threshold from other VEPP-2M groups [14], [15], [16], CERN [17] as well as the measurements from 483 to 1096 MeV at Orsay [18]. At higher energies this reaction was systematically studied by DM2 [19] (Fig.1). Although the precision is worse compared to the low energy region, the contribution of this energy range is suppressed. The results of the integration give for the ratio of branchings R_l:

$2m_\pi$ - 1.4 GeV	1.352	$\pm$ 0.035
1.4 GeV - m_τ	0.028	$\pm$ 0.005
Total	1.380	$\pm$ 0.035

The absolute branching ratio is

$$B(\tau^- \to \pi^-\pi^0\nu_\tau) = \begin{cases} (24.9 \pm 0.7)\%\,\mathrm{CVC} \\ (24.9 \pm 0.5)\%\,\mathrm{RPP-94} \end{cases}$$

Mass spectra show a prominent ρ-meson, non-resonant contribution is small. Agreement of the experimental spectrum with the CVC prediction is rather good, but definite statements will be possible only after a joint analysis performed by τ and e^+e^- groups taking into account new data coming from CMD-2 at Novosibirsk with an accuracy better than 1% [20].

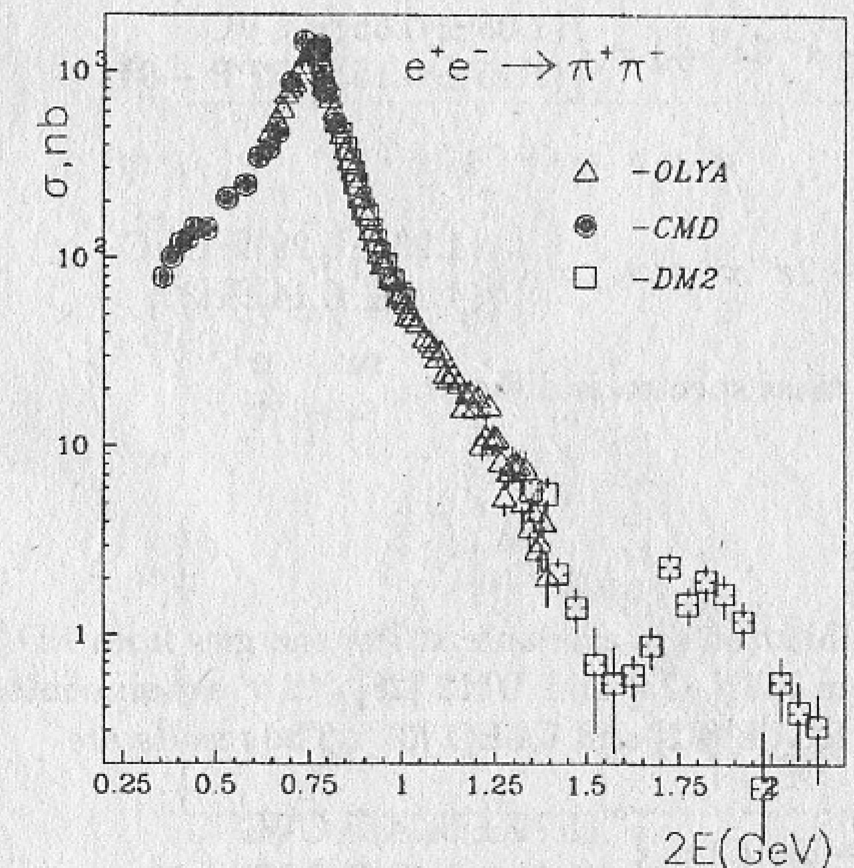

Figure 1.

3 $\tau \to 4\pi\nu_\tau$

There are two channels in the four-pion production in e^+e^- annihilation: $\pi^+\pi^-\pi^0\pi^0$ and $2\pi^+2\pi^-$. OLYA [21, 22] and ND [23] who scanned the energy region from about 640 to 1400 MeV at VEPP-2M provided results on both, while CMD [24] measured the cross section of the latter in 9 points from 1019 up to 1403 MeV. The values of the cross section determined by ND are usually higher than those of OLYA in both reaction channels, however they are within systematic uncertainties which are estimated by the authors to be 15% and 10% respectively for ND and 20% in both cases for OLYA. CMD claimed a 10% systematic uncertainty and within it agreed with both ND and OLYA. At higher energies we used the data from M3N [25], DM1 [26] and DM2 [27, 28] (Figs.2,3).

Also two decay modes are possible for the τ decay: $\pi^-3\pi^0\nu_\tau$ and $2\pi^-\pi^+\pi^0\nu_\tau$. From isotopic symmetry [29] one obtains:

$$\sigma_1 = 0.5\sigma_{2\pi^+2\pi^-}$$

$$\sigma_2 = 0.5\sigma_{2\pi^+2\pi^-} + \sigma_{\pi^+\pi^-2\pi^0}$$

As a result one obtains

$$B(\tau^- \to \pi^-3\pi^0\nu_\tau) = \begin{cases} (1.08 \pm 0.05)\%\,\mathrm{CVC} \\ (1.15 \pm 0.15)\%\,\mathrm{RPP-94} \end{cases}$$

and

$$B(\tau^- \to 2\pi^-\pi^+\pi^0\nu_\tau) = \begin{cases} (4.20 \pm 0.29)\%\,\mathrm{CVC} \\ (4.45 \pm 0.14)\%\,[30] \end{cases}$$

Comparison of mass spectra is difficult.

4 $\tau \to \omega\pi\nu_\tau$

Data for e^+e^- annihilation are available at low energies from ND [31] and at higher energies from M3N [25] and DM2 [28]. In τ experiments this mode was observed by ARGUS [32] and CLEO [33]. The results are

$$B(\tau \to \omega\pi\nu_\tau) = \begin{cases} (1.79 \pm 0.14)\%\,\mathrm{CVC} \\ (1.60 \pm 0.49)\%\,\mathrm{RPP-94} \end{cases}$$

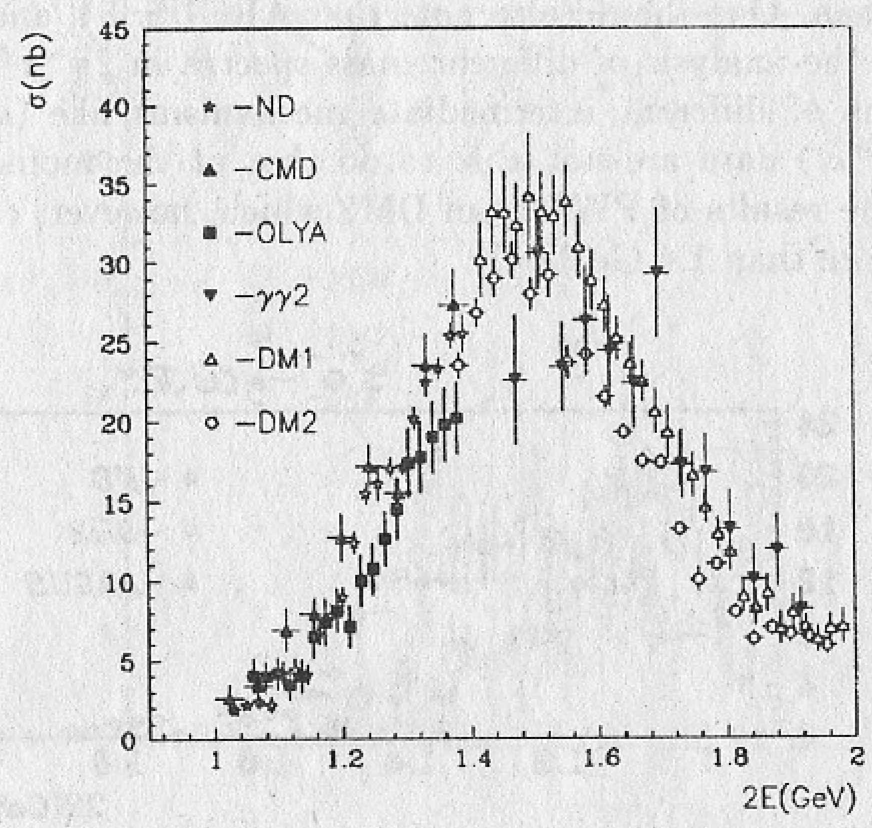

Figure 2.

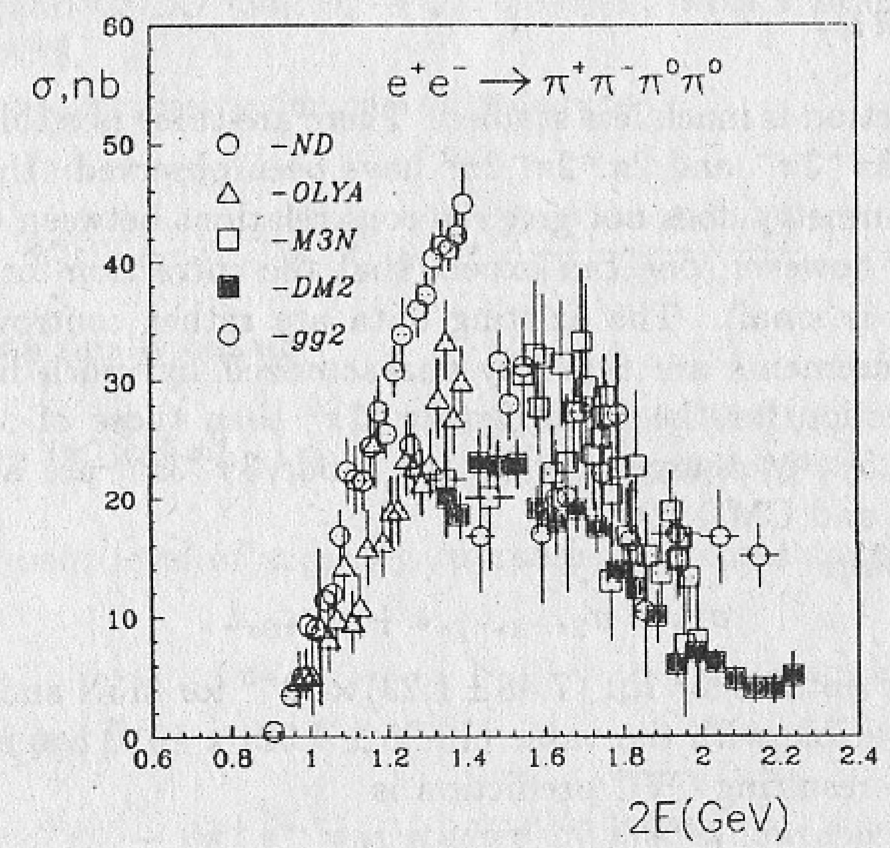

Figure 3.

Mass spectra agree (see Fig.4), but the τ statistics is not yet sufficient for precise comparison. One should also note that ARGUS [34] and CLEO [35] determine from the analysis of different mass spectra in $2\pi^-\pi^+\pi^0\nu_\tau$ events relative fractions of different intermediate mechanisms like $(a_1(1260)\pi)^-$, $(\rho\pi)^0\pi^-$ etc. e^+e^- data are not able to do that at the moment, one can only hope for the results of PWA from DM2 which, however, can cover the energy range more than 1.4 GeV only.

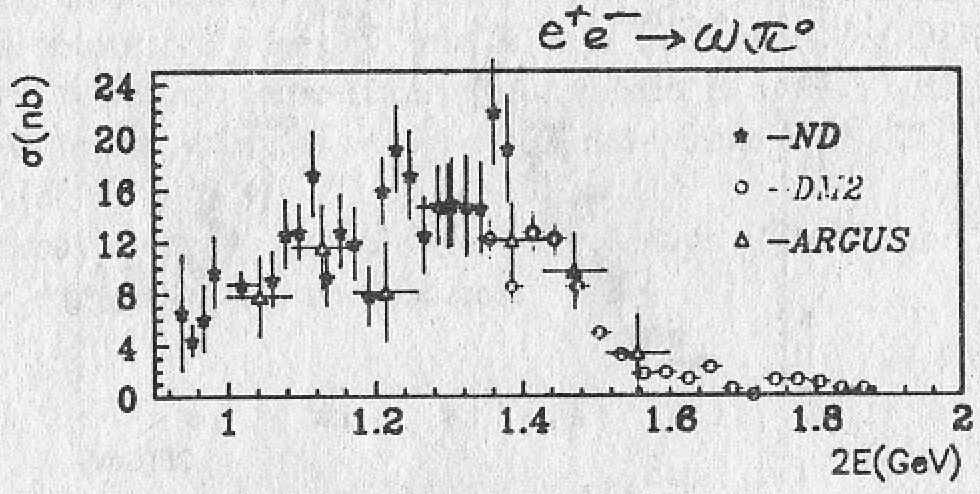

Figure 4.

5 $\tau \to 6\pi\nu_\tau$

Six pion production is much less studied. There are three possible final states of which only $3\pi^+3\pi^-$ and $2\pi^+2\pi^-2\pi^0$ have been observed. Unfortunately, the isotopic symmetry does not give rigorous relations between different isotopic partners, however, one can expect that the correction for the missing part $\pi^+\pi^-4\pi^0$ is small. The existing data are rather controversial. The $\gamma\gamma 2$ [36] measurements are typically characterized by much higher values of the cross section for the mode $2\pi^+2\pi^-2\pi^0$ than those of M3N[25] and DM2 [27] (Fig.5). Measurements for the mode $3\pi^+3\pi^-$ are also available from DM1 [37] and CMD [24].
We will use a sum

$$\sigma_{6\pi} = \sigma_{2\pi^+2\pi^-2\pi^0} + \sigma_{3\pi^+3\pi^-}.$$

As a result, one obtains for R_l: $(7.48 \pm 1.29) \times 10^{-3}$ for M3N and DM2 which is hardly compatible with the value $(18.98 \pm 4.32) \times 10^{-3}$ coming from $\gamma\gamma 2$ and DM1. The resulting CVC prediction is

$$B(\tau^- \to 6\pi^-\nu_\tau) = (0.134 \pm 0.023)\%$$

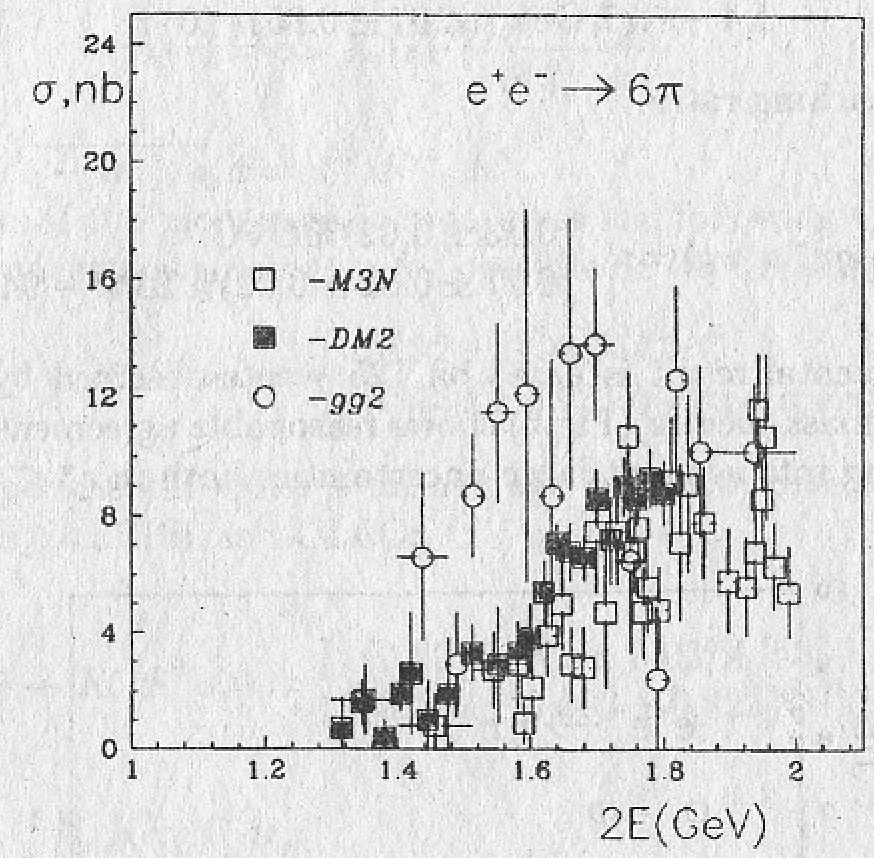

Figure 5.

In the case of τ only one of three possible decay modes has been observed by HRS [38] and CLEO [35]: $\tau \to 3\pi^-2\pi^+\pi^0\nu_\tau$ with a branching ratio of $(0.021 \pm 0.008)\%$.

From isospin symmetry one can only deduce

$$B(\tau^- \to 3\pi^-2\pi^+\pi^0\nu_\tau) \geq \frac{B(\tau^- \to 6\pi^-\nu_\tau)}{5}$$

so that one can finally obtain

$$B(\tau^- \to 3\pi^-2\pi^+\pi^0\nu_\tau) = \begin{cases} \geq (0.027 \pm 0.005)\% \, \mathrm{CVC} \\ (0.021 \pm 0.008)\% \, \mathrm{RPP-94} \end{cases}$$

At the present level of accuracy comparison of mass spectra is not very informative.

6 $\tau \to \eta\pi\pi\nu_\tau$

The reaction $e^+e^- \to \eta\pi^+\pi^-$ was studied by [39] at low energy and by [40] and [41] at high energy. The calculation gives for R_l

1.2 – 1.4 GeV $(1.16 \pm 0.52) \cdot 10^{-3}$
1.4 – 1.77 GeV $(6.07 \pm 0.85) \cdot 10^{-3}$

and for the branching ratio

$$B(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = \begin{cases} (0.13 \pm 0.02)\%\,\mathrm{CVC} \\ (0.17 \pm 0.02 \pm 0.02)\%\,\mathrm{RPP-94} \end{cases}$$

The experimental result is based on 125 events observed by CLEO [42]. Comparison of mass spectra (Fig.6) shows reasonable agreement which is not surprising taking into account large uncertainties both in e^+e^- and τ data.

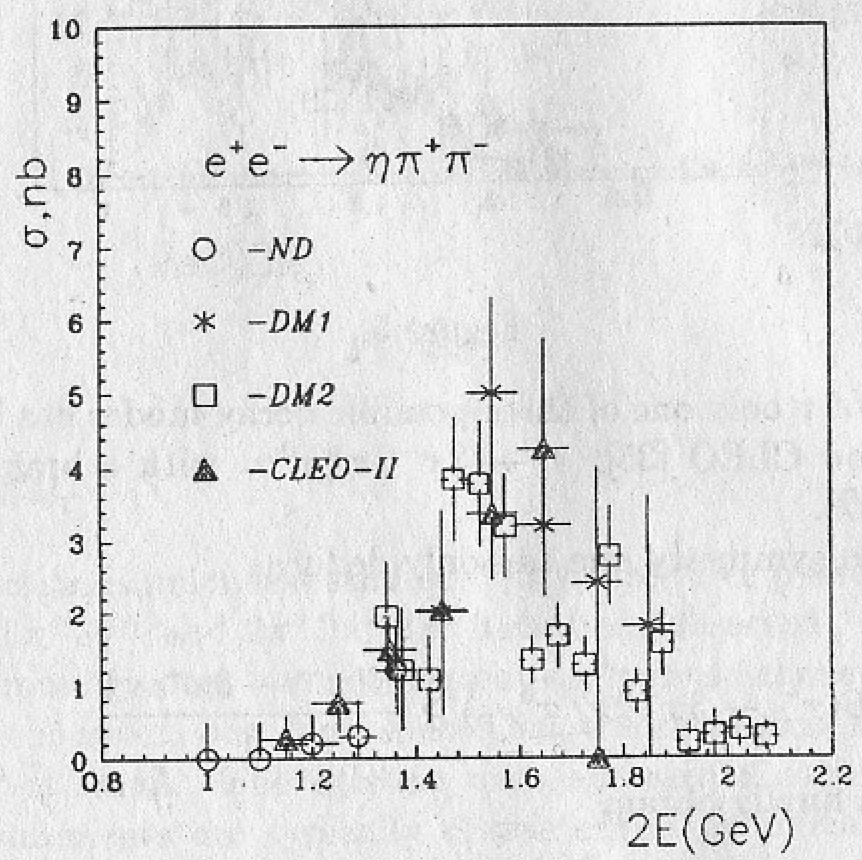

Figure 6.

7 $\tau^- \to K^- K^0 \nu_\tau$

Production of kaon pairs was studied by OLYA [44, 45], DM1 [46],[47] and DM2 [48]. It is difficult to select a small isovector part from the dominating isoscalar one. One can try to use the SU(3) considerations and relate it to the cross section of pion pair production. After applying kinematical corrections one obtains

$$\sigma_h(s) = \sigma_{\pi^+\pi^-}(s)\frac{(\beta^3_{K^-} + \beta^3_{K^0})}{(4\beta^3_{\pi^-})},$$

where $\beta_x = \sqrt{1 - 4m_x^2/s}, x = \pi^-, K^-, K^0$.

Integration of the pion cross section gives the following CVC prediction where a 25% uncertainty accounts for possible SU(3) breaking effects:

$$B(\tau^- \to K^- K^0 \nu_\tau) = \begin{cases} (0.12 \pm 0.03)\%\,\mathrm{CVC} \\ (0.130 \pm 0.031)\%\mathrm{Experiment} \end{cases}$$

where the experimental value is an average from [49] based on two recent observations by ALEPH and CLEO:

$$B(\tau^- \to K^- K^0 \nu_\tau) = \begin{cases} (0.29 \pm 0.12 \pm 0.03)\%\,[50] \\ (0.123 \pm 0.023 \pm 0.023)\%\,[51] \end{cases}$$

8 $\tau^- \to (K\bar{K}\pi)^- \nu_\tau$

If $K\bar{K}$ are in the ϕ state, one can use the existing upper limits from [52],[24], [23] and obtain

$$B(\tau^- \to \phi\pi^-\nu_\tau) < 0.06\%$$

which does not contradict to the CLEO upper limit of 0.1% [53].

DM1 [54] and DM2 [55] measured also cross sections of the reaction $e^+e^- \to KK_S\pi$ and made an attempt to isolate the contributions of $I = 0$ and $I = 1$. Using their results, one obtains

$$B(\tau^- \to K^+K^-\pi^-\nu_\tau) = (0.044 \pm 0.032)\%\mathrm{CVC}$$

to be compared with the inclusive measurement by TPC/2γ [56]

$$B(\tau^- \to K^+K^-\pi^-\nu_\tau + \mathrm{neutrals}) = (0.15 \pm 0.08)\%$$

which is in agreement with the previous results from DELCO, ARGUS and CLEO [49].

This estimate should be considered as a lower bound only although there are arguments that the axial current contribution is small [8].

Results of our calculations are summarized in the Table which also presents current world average values and other theoretical predictions.

Branching Ratios of $\tau^- \to X^-\nu_\tau$, %			
Hadronic State X	RPP-94	This Work	Other Works
$\pi^-\pi^0$	24.9 ± 0.5	24.9 ± 0.7	24.3 [3]
			24.2 ± 0.9 [7]
			24.2 ± 0.8 [11]
			24.7 ± 1.1 [43]
$\pi^-3\pi^0$	1.15 ± 0.15	1.08 ± 0.05	1.1 [3]
			1.03 ± 0.18 [11]
$2\pi^-\pi^+\pi^0$	4.8 ± 0.4	4.20 ± 0.29	5.4 [3]
			4.83 ± 0.72 [11]
$\omega\pi^-$	1.60 ± 0.49	1.79 ± 0.14	2.32 ± 0.41 [11]
			1.01 [10]
$6\pi^-$		0.13 ± 0.02	¡ 0.47 [3]
			0.14 ± 0.05 [11]
$3\pi^-2\pi^+\pi^0$	0.021 ± 0.006	0.027 ± 0.005	
$\eta\pi^-\pi^0$	0.170 ± 0.028	0.130 ± 0.018	0.14 ± 0.05 [11]
			$0.2 - 0.3$ [5]
			0.15 [6]
K^-K^0	0.130 ± 0.031	0.12 ± 0.03	0.5 [3]
			0.16 ± 0.02 [11]
$\phi\pi^-$	< 0.1	< 0.06	
$\pi^-K^+K^-$	0.17 ± 0.08	0.044 ± 0.032	0.16 ± 0.05 [11]
			$0.21 - 0.38$ [8]
$\pi^-K^0K^0$		0.044 ± 0.032	0.16 ± 0.05 [11]
			$0.21 - 0.38$ [8]

9 Conclusions

— CVC predicts well the branching ratios:

$$\Sigma B(\tau^- \to X^-\nu_\tau) = \begin{cases} (30.50 \pm 0.76)\%\,\mathrm{CVC} \\ (30.99 \pm 0.55)\%\,\mathrm{RPP-94} \end{cases}$$

— Within the current accuracy mass spectra predicted by CVC and observed experimentally agree, in future joint efforts of τ and e^+e^- groups are necessary.

— No second class currents are observed:

$$B(\tau^- \to \eta\pi^-\nu_\tau) < 3.4 \times 10^{-4}$$

and in $\tau^- \to \omega\pi^-\nu_\tau$ decay the $(\omega\pi^-)$ state has $J^P = 1^-$, the fraction of 1^+ being less than 13%.

— τ decays become competetive to e^+e^- in studying resonances

— For future high precision CVC tests e^+e^- experiments are necessary in which the energy range from the pion pair production threshold until the τ mass will be studied with one detector. In the ideal case the same detector will be used for τ decay studies (c-τ-factory).

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