ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

S.I. Eidelman and V.N. Ivanchenko

# $e^+e^-$ ANNIHILATION INTO HADRONS AND EXCLUSIVE $\tau$ DECAYS

PREPRINT 90-147

НОВОСИБИРСК

# $e^+e^-$ Annihilation into Hadrons and Exclusive $\tau$ Decays*)

*S.I. Eidelman and V.N. Ivanchenko*

Institute of Nuclear Physics
630090, Novosibirsk, USSR

ABSTRACT

New calculations of the branching ratios of the $\tau$-lepton hadronic decays are presented based on the conserved-vector-current hypothesis and the whole bulk of data on electron-positron annihilation into hadrons. Recent results from the Neutral Detector (ND) at VEPP-2M and DM2 detector at DCI are included. Perspectives of future measurements of hadronic cross sections in Novosibirsk are discussed.

*) Talk given at the workshop on $\tau$-lepton physics, Orsay, France, September 24-27, 1990.



## INTRODUCTION

At the present time the probabilities of the large number of $\tau$-lepton decays into hadrons are known [1] allowing different mutual tests of theory and experiment. One of the important theoretical conceptions is the conserved-vector-current hypothesis providing a relation between spectral functions in decays $\tau^- \to h^- \nu_\tau$ with cross sections of $e^+e^- \to h^0$ where $h$ is a hadronic system with quantum numbers $I^G J^{PC} = 1^+1^{--}$. Within this hypothesis the branching ratios of various decay modes have been predicted [3,4] in reasonable agreement with experiment. In the experiments of ARGUS [5] and ND [5,6] spectral functions obtained in tau decays and $e^+e^-$ annihilation have been compared for the first time.

New data from $e^+e^-$ annihilation into hadrons [6], more detailed data of CELLO, ARGUS, beginning of experiments with CLEO-II and four detectors at LEP as well as widely discussed projects of charm-tau factories require new more accurate calculations of the branching ratios of $\tau$ decays [8]. Additional motivation is provided by the recent result [9] of calculation of the $B(\tau^- \to \pi^- \pi^0 \nu_\tau)$ differing from the previous value in Ref. 3.

In this paper we used both well known data from the detectors CMD and OLYA at VEPP-2M [10-13], M3N [14], DM1 [15,16], DM2 [17] at DCI, MEA [18] and $\gamma\gamma 2$ [19] at ADONE as well as recent data from ND [6] and DM2 [20,21]. Special attention was paid to determination of the statistical and systematic uncertainties of the calculation. Possibilities of future experiments with SND and CMD-2 at VEPP-2M in Novosibirsk relevant to our problem are discussed [22].

## CALCULATION METHOD

The following expression was used for the calculation of the branching ratios of the hadronic tau decays:

$$B(\tau^- \to h^- \nu_\tau) = B(\tau^- \to e^- \bar{\nu}_e \nu_\tau) \frac{3\cos^2\vartheta_c}{2\pi\alpha^2 m_\tau^8} I, \qquad (1)$$

$$I = \int_0^{m_\tau^2} \sigma_h(s) g(s)\, ds, \qquad g(s) = s(m_\tau^2 - s)^2 (m_\tau^2 + 2s),$$

where $\vartheta_c$ is the Cabibbo angle, $\sigma_h(s)$ is the corresponding cross section of $e^+e^-$ annihilation.

For each process and for results of each experiment the integrals were calculated separately. To this end the integration region was divided into two parts: from threshold of the specific channel to $(1.4\ \mathrm{GeV})^2$ and from $(1.4\ \mathrm{GeV})^2$ to $m_\tau^2$. In the first region data of experiments at VEPP-2M were integrated, whereas in the second one data of ADONE and DCI were used. Integration region was subdivided into intervals and the following simplified formula was used to calculate the quantity $I_i$ in each such interval $s_i \pm \Delta s$:

$$I_i = \sigma_h(s_i) G_i, \qquad G_i = \int_{s_i - \Delta s}^{s_i + \Delta s} g(s)\, ds. \qquad (2)$$

After that the sum was calculated

$$I = \sum_i I_i. \qquad (3)$$

This method essentially differs from those in previous calculations [3,4,9] since we are integrating directly over the experimental $e^+e^-$ cross sections rather than over a fit to them. In this way we avoid possible model dependence as well as ambiguity of the data interpretation in the energy range near 1.4 GeV. A systematic uncertainty included a systematic error of the calculation according to (2). A statistical error is obtained from the following formula

$$\delta I = \sqrt{\sum_i (G_i \delta\sigma_h(s_i))^2}, \qquad (4)$$

where $\delta\sigma_h(s_i)$ is an experimental statistical error of cross section measurement.

After calculation of the integrals a systematic error was added to the statistical one in quadrature. In each energy range results of integration were averaged over data of different groups. These results are presented in Tabl. 1. After that the values of the branching ratios were determined (Tabl. 2).

## RESULTS

The decay mode $\tau^- \to \pi^- \pi^0 \nu_\tau$ as well as the cross section of the reaction $e^+e^- \to \pi^+\pi^-$ have been measured with good accuracy. Our result (Tabl. 2) coincides with that of Ref. 9 and somewhat differs from the old calculation [3]. The isoscalar contribution due to the transition $e^+e^- \to \omega \to \rho$ is equal to 0.6% and was taken into account.

The decay mode $\tau^- \to \omega\pi^- \nu_\tau$ has been reliably observed by ARGUS [5] and CLEO [23]. The reaction $e^+e^- \to \omega\pi^0$ was directly studied by ND [7] and with worse precision by M3N [14].

The decay mode $\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$ has been observed in [5,24]. There are two isotopic partners of the produced hadronic system in $e^+e^-$ annihilation. From isotopic invariance one can find the following relation [3,25].

$$\sigma_h(s) = \sigma_{\pi^+\pi^-\pi^0\pi^0}(s) + \frac{1}{2}\,\sigma_{\pi^+\pi^-\pi^+\pi^-}(s). \qquad (5)$$

The cross sections of $e^+e^- \to 4\pi$ have been measured in many experiments (Tabl. 1), the difference between them is usually within systematic errors.

The decay mode $\tau^- \to \pi^-\pi^0\pi^0\pi^0\nu_\tau$ is known with much smaller



Table 1

**Contribution of the Cross Sections of $e^+e^-$ Annihilation to $\tau$-Lepton Branching Ratios**

| Process | Experim. | $E$, GeV | $B(\tau^- \to h^- \nu_\tau)$,% | System err.,% | Average,% | Ref. |
|---|---|---|---|---|---|---|
| $\pi^+\pi^-$ | OLYA | <0.84 | 17.66±0.18 | 4 | 17.73±0.73 | [11] |
| | CMD | | 17.84±0.51 | 3.5 | | |
| | OLYA | 0.84÷1.01 | 4.03±0.05 | 6 | 4.03±0.25 | [11] |
| | OLYA | 1.01÷1.4 | 1.60±0.03 | 12 | 1.60±0.19 | [11] |
| | DM2 | >1.4 | 0.05±0.01 | 10 | 0.05±0.01 | [21] |
| $\omega\pi^0$ | ND | <1.4 | 1.35±0.07 | 8 | 1.35±0.13 | [6] |
| | M3N | >1.4 | 0.88±0.32 | 10 | 0.88±0.32 | [14] |
| $\pi^+\pi^-\pi^+\pi^-$ | ND | <1.4 | 1.07±0.01 | 10 | 1.07±0.07 | [6] |
| | OLYA | | 0.90±0.03 | 20 | | [13] |
| | CMD | | 1.11±0.05 | 7 | | [10] |
| | MEA | >1.4 | 0.86±0.09 | 10 | 1.06±0.07 | [18] |
| | DM2 | | 1.05±0.02 | 10 | | [17] |
| | $\gamma\gamma2$ | | 0.97±0.07 | 15 | | [19] |
| | DM1 | | 1.24±0.03 | 10 | | [15] |
| | M3N | | 1.31±0.14 | 10 | | [14] |
| $\pi^+\pi^-\pi^0\pi^0$ | ND | <1.4 | 2.60±0.05 | 15 | 2.15±0.26 | [6] |
| | OLYA | | 1.77±0.07 | 20 | | [12] |
| | M3N | >1.4 | 1.00±0.13 | 10 | 1.04±0.08 | [14] |
| | DM2 | | 1.15±0.03 | 10 | | [17] |
| | $\gamma\gamma2$ | | 0.91±0.08 | 15 | | [19] |
| $\eta\pi^+\pi^-$ | ND | <1.4 | 0.02±0.03 | 10 | 0.02±0.03 | [6] |
| | DM1 | >1.4 | 0.13±0.03 | 10 | 0.11±0.014 | [16] |
| | DM2 | | 0.10±0.01 | 10 | | [20] |
| $(6\pi)^-$ | M3N | <1.4 | 0.02±0.02 | 10 | 0.02±0.02 | [14] |
| | M3N | >1.4 | 0.12±0.04 | 10 | 0.16±0.04 | [14] |
| | $\gamma\gamma2$ | | 0.34±0.06 | 15 | | [19] |
| $K\bar{K}(I=1)$ | CMD, OLYA | <1.4 | 0.10 | | 0.10 | [11] |
| | DM2 | >1.4 | 0.01 | | 0.01 | [21] |

accuracy [1,24], there is also the unpublished result of Crystal Ball [8]. On the other hand, the calculation of its branching ratio from $e^+e^-$ annihilation is rather accurate since in this case $\sigma_h(s)$ depends on the cross section of $e^+e^-\to\pi^+\pi^-\pi^+\pi^-$ only [3,25]

$$\sigma_h(s)=\frac{1}{2}\sigma_{\pi^+\pi^-\pi^+\pi^-}(s). \qquad (6)$$

For the decay mode $\tau^-\to\eta\pi^-\pi^0\nu_\tau$ only upper limit exists. Its isotopical partner in $e^+e^-$ annihilation $e^+e^-\to\eta\pi^+\pi^-$ has been rather well measured. The expected value of the branching ratio is one order of magnitude lower than the existing limit.

The decay mode $\tau^-\to K^-K^0\nu_\tau$ has not been observed too. It is experimentally impossible to extract from the cross section $e^+e^-\to K\bar{K}$ its isovector part. The isoscalar contribution is large both in $e^+e^-\to K^+K^-$ and $e^+e^-\to K_SK_L$ channels, and dominates in the $\phi$-meson region. Therefore, following the approach of Ref. 6, we use the SU(3) relation [26]

$$\sigma_h(s)=\sigma_{\pi^+\pi^-}(s)\,\frac{\beta^3_{K^-}+\beta^3_{K^0}}{4\beta^3_{\pi^-}},\quad \beta_x=\sqrt{1-4m_x^2/s},\quad x=\pi^-,K^-,K_S. \qquad (7)$$

We estimate the accuracy of this calculation to be about 20%. The obtained value of the branching ratio (Tabl. 2) is only two times smaller than the upper limit [1] and is 5 times smaller than the previous estimate [3].



The decay $\tau^-\to(6\pi)^-\nu_\tau$ is characterized by three different final states of the hadronic system. Only one of them has been observed $\tau^-\to2\pi^+3\pi^-\pi^0\nu_\tau$ [1]. Data from $e^+e^-$ annihilation are also rather scarce [14,19] and allow the calculation of the total branching ratio. From the isotopical relation [3] $B(\tau^-\to2\pi^+3\pi^-\pi^0\nu_\tau)\geq\frac{1}{5}B(\tau^-\to(6\pi)^-\nu_\tau)$ a lower limit of the branching ratio can be obtained (Tabl. 2) which is quite consistent with the measured value $B(\tau^-\to2\pi^+3\pi^-\pi^0\nu_\tau)$ = (0.051±0.022)%.

The decay mode $\tau^-\to\phi\pi^-\nu_\tau$ has not been studied. For the corresponding cross section only upper limits exist [6,10,16]. From them one obtains the limit for the branching ratio at 90% CL. This decay is interesting since it can shed light on the nature of the c(1480) resonance [27]. Two opposite points of view as to its quark contents exist. In Ref. 27 it is considered as an exotic one. In another model [28] c(1480) is manifestation of the ρ(1450) resonance. From the most optimistic model of [28] we obtained the value of branching ratio to be 4.5 times smaller than our upper limit. If c(1480) is exotic, the branching ratio will be much smaller.

## DISCUSSION

Data from $e^+e^-$ annihilation on different final states allow to predict branching ratios with smaller errors than in direct measurements. Most of our results in Tabl. 2 are in good agreement both with experiment and previous calculations [3, 4, 9]. Our accuracy is determined by systematic uncertainties of the measurements varying from 5 to 20%. Therefore a new cycle of $e^+e^-$ experiments is needed with considerably smaller systematic errors.

Two experiments CMD-2 and SND are planned at VEPP-2M in the energy region below 1.4 GeV [22]. These detectors will

Table 2

**τ-Lepton Branching Ratios**

| Decay | Branching ratio,% | | |
|---|---|---|---|
| | This work | PDG[1] | Other works |
| $\tau^- \to \pi^- \pi^0 \nu_\tau$ | 23.4±0.8 | 22.7±0.8 | 21.8 [3]<br>23.4±0.9 [9] |
| $\tau^- \to \omega \pi^- \nu_\tau$ | 2.2±0.3 | 1.6±0.5 | |
| $\tau^- \to \pi^+ \pi^- \pi^- \pi^0 \nu_\tau$ | 4.3±0.3 | 4.4±1.6 | 4.9 [3] |
| $\tau^- \to \pi^- \pi^0 \pi^0 \pi^0 \nu_\tau$ | 1.07±0.06 | 3.0±2.7 | 1. [3] |
| $\tau^- \to \eta \pi^- \pi^0 \nu_\tau$ | 0.13±0.02 | <1.1 | ~0.15 [4] |
| $\tau^- \to K^- K^0 \nu_\tau$ | 0.11±0.03 | <0.26 | 0.5 [3] |
| $\tau^- \to (6\pi)^- \nu_\tau$ | 0.19±0.04 | | <0.42 [3] |
| $\tau^- \to \phi \pi^- \nu_\tau$ | <0.09<br>0.02*) | | |

*) – the prediction using the model from Ref.28.



cover a much larger solid angle, have much better energy and space resolution, particle identification providing higher detection efficiency and smaller systematic errors compared to the previous experiments. However, as follows from Tabl. 1, if these experiments achieve an accuracy about 5%, the calculation uncertainty will be determined by data of DCI and ADONE.

Thus, in near future one can expect the improvement of the calculation by a factor 2, but not higher. Further progress in $e^+e^-$ physics is possible if experiments at the energy higher than 1.4 GeV are performed. It is naturally assumed that the accuracy of the τ branching ratios will be much higher due to experiments CLEO-II, at LEP detectors and at the charm-tau factory [8].

In conclusion note than a check of the conservation of vector current provides a unique opportunity of testing experimental data obtained under completely different conditions and thereby a detailed check of the electroweak theory.

## REFERENCES


1. Review of Particle Properties, Particle Data Group, 1990.
2. *Y.S. Tsai.* Phys. Rev. D4(1971)2821; *H.B. Thacker and J.J. Sakurai.* Phys. Lett. 36B(1971)103.

3. *F.J. Gilman and D.H. Miller.* Phys. Rev D17 (1978)1846; *F.J. Gilman and S.H. Rhie.* Phys. Rev D31 (1985)1066.
4. *F.J. Gilman.* Phys. Rev D35 (1987) 3541.
5. *N. Albrecht et al.* Phys. Lett. 185B (1987)223.
6. *S.I. Dolinsky et al.* Preprint INP 89-68, Novosibirsk, 1989; Preprint INP 89-104, Novosibirsk, 1989; Submitted to Phys. Reports.
7. *S.I. Dolinsky et al.* Phys. Lett. 174B (1986)453.
8. Proceedings of the Workshop on $\tau$-lepton Physics, Orscay, France, September 24-27, 1990.
9. *J.H. Kuhn and A. Santamaria.* Preprint MPI-PAE/PTh 17/90, 1990, Submitted to Z. Phys. C.
10. *G.V. Anikin et al.* Preprint INP 83-85, Novosibirsk, 1983; *L.M. Barkov et al.* Sov. Jour. Nucl. Phys. 47(1988)248.
11. *L.M. Barkov et al.* Nucl. Phys. B256(1985)365.
12. *L.M. Kurdadze et al.* JETP Lett. 43(1988)643.
13. *L.M. Kurdadze et al.* JETP Lett. 47(1988)512.
14. *G. Cosme et al.* Nucl. Phys. B152(1979)215; *C.Paulot,* Preprint LAL-79/14, Orsay, 1979.
15. *A. Cordier et al.* Phys. Lett. 109B(1982)129.
16. *B. Delcourt et al.* Phys. Lett. 113B(1982)93.
17. *J.E. Augustin et al.* Preprint LAL 83-21, Orsay, 1983.
18. *B. Esposito et al.* Nuovo Cim. Lett. 28(1980)195.
19. *C. Bacci et al.* Nucl. Phys. B184(1981)31.
20. *A. Antonelli et al.* Phys. Lett. 212B(1988)133.
21. *D. Bisello et al.* Phys. Lett. 220B(1989)321.



22. *V.N. Ivanchenko.* Proc. of the 3 Inter. Conf. on Hadr Spectr., Ajaccio, France, 23-27 September,1989.
23. *P. Baringer et al.* Phys. Rev. Lett. 59(1987)1993.
24. *H.J. Behrend et al.* Z.Phys. C 23(1985)103.
25. *I.M. Shmushkevich.* Dokl. Akad. Nauk SSSR 103(1955)235.
26. *N.M. Kroll et al.* Phys. Rev 157(1967)1376.
27. *S.I. Bitukov et al.* Phys. Lett. 188B(1987)383; *L.G. Landsberg.* Sov. Phys.-Uspekhi 160(1990)1.
28. *N.N. Achasov and A.A. Kozhevnikov.* Phys. Lett. 207I (1988)99.

*S.I. Eidelman and V.N. Ivanchenko*

**$e^+e^-$ Annihilation into hadrons and exclusive $\tau$-decays**

*С.И. Эйдельман, В.Н. Иванченко*

**Новое вычисление относительных вероятностей эксклюзивных распадов $\tau$-лептона**

Ответственный за выпуск: С.Г. Попов

---

Работа поступила - 11 ноября 1990 г.
Подписано к печати 18.12 1990 г.
Формат бумаги 60×90 1/16
Объем 0,8 п.л., 0,7 уч.-изд.л.
Тираж 250 экз. Бесплатно. Заказ 147.

---

Ротапринт ИЯФ СО АН СССР,
г. Новосибирск, 90.