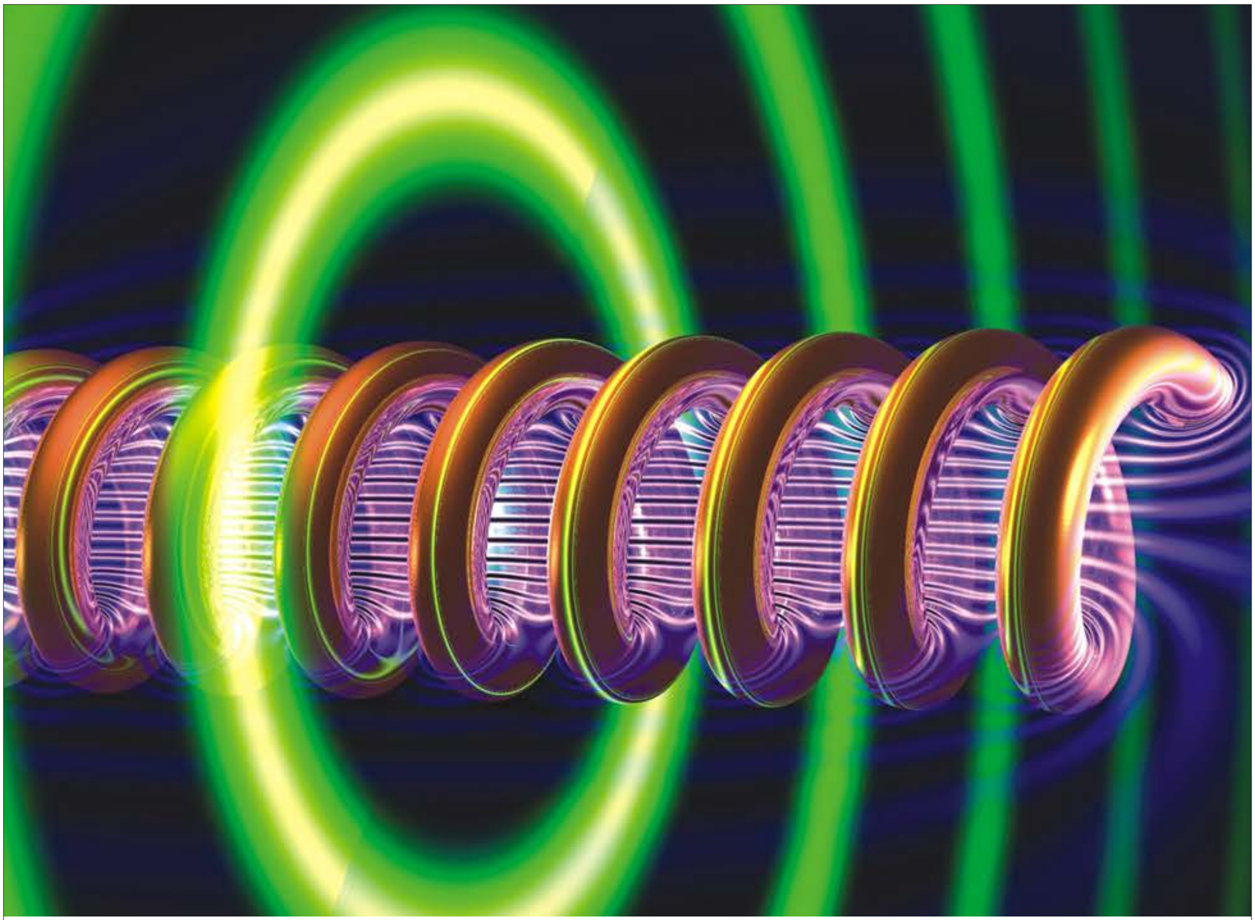

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# Study of the Hadronic Tau Decays Spectrum by using the New Experimental Data

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## ABSTRACT

The tau lepton is the heaviest and the only lepton that is able to decay into hadrons, therefore it provides a perfect tool to test the structure of the weak currents and the universality of their couplings to the gauge bosons. In the framework of the standard model, the w boson has both vector and axial vector components and can be coupled to hadronic states with spin-parity: $J^P = 0^-$, $0^+$, $1^-$, $1^+$. In the non- strange tau decays which G-parity is conserved, the separation of vector and axial-vector components in hadronic final states, can be observed directly by pions. Even number of pions (with G-parity = 1) are related to vector states and odd number of pions (with G-parity = -1) are related to axial-vector states. In this study, the widths of some dominant hadronic (semi-leptonic) tau decays are calculated and compared with new experimental data such as BABAR, ALEPH, DELPHI, FRASCATI and ORSAY. Since branching fraction ratio for two decay is equal with those decay width, by determining decay widths, we could be predict precise value for ratio of branching fractions.

**Key words:** Taw decays, lepton, BABAR, ALEPH, spectral functions

## INTRODUCTION

The tau lepton is the only lepton for which hadronic decay modes are kinematically allowed. Tau lepton is the heaviest member of the third generation of elementary particles and it has own lepton number and one associated neutrino does not interact through strong interactions. The σ lepton provides an ideal tools to study the interaction between the weak charged current and hadrons which is not available by the other leptons. Hadrons from σ decays are produced by the weak charged current from the QCD vacuum. The hadronic physics factors and the characteristic of each decay channels are related by spectral functions as far as the total decay rate. Spectral functions parameterize the transition probability of creating hadrons out of the QCD vacuum (out of the charged weak current) as a function of hadronic mass (Gentile and Pohl, 1996). In heavy lepton decay to hadronic final state, only final states with J = 1 or J = 0 are allowed which these final states can have either positive or negative parity. Scalar and axial-vector mesons have positive parity but vector and pseudo scalar mesons have negative parity. In these decays, fundamental quantities, called spectral functions, describe properties of the hadronic systems. Specific relationships and predictions for these spectral functions can be obtained using CVC, PCAC and certain assumptions about the symmetries, as is usual in the phenomenology of weak hadronic decays (Berger *et al.*, 1988).

Table 1: Properties of the weak current

| Axial vector current | Vector current | Property |
|---|---|---|
| I | 1 | 1 |
| G | +1 | -1 |
| $J^P$ | $0^+$ (Strange), $1^-$ | $0^-$, $1^+$ |

The vector current can produce scalar ($0^+$) and vector ($1^-$) hadronic final states, The axial-vector current can produce pseudoscalar ($0^-$) and axial-vector ($1^+$) hadronic final states

**Properties of the weak charged current:** It is easy to shown that the vector and axial-vector currents are even and odd, respectively under G-parity. Recall that G-parity operation is a combination of a rotation in isospin space and charge conjugation. Table 1 shows the properties of the weak current.

If vector current is conserved which is true for non-strange final states, it is impossible to have the scalar ($0^+$) in the final states. The decay products of vector current interactions are always vectors ($1^-$). Strange decays are not obeyed from CVC, so the final states can be scalar ($0^+$) or vector ($1^-$).

In the non-strange tau decays which G-parity is conserved, the separation of vector and axial-vector components in hadronic final states, only have been observed by pions. Even number of pions (with G-parity = 1) is related to vector states and odd number of pions (with G-parity = -1) is related to axial-vector states (Lyon, 2004). The hypotheses Conserved Vector Current (CVC) that used to describe the weak current and it's conjugate, together with the electromagnetic current, form an isospin triplet of conserved currents. For even G-parity, only the vector current contributes in final states and therefore CVC connects the decay rate to the cross-section for $e^+ e^- \rightarrow$hadrons.

## HADRONIC TAU DECAYS

The tau lepton is the only lepton which is sufficiently heavy to be able to decay into hadrons. The theoretical framework for these decays is based on the well tested assumptions that the structure of weak hadronic current is (V-A). The Feynman diagram for hadronic tau decay is shown in Fig. 1.

where, $v_1$, $a_1$, $v_0$ and $a_0$. Tsai has been derived the general form of hadron production in heavy-lepton decays through the (V-A) interactions by (Tsai, 1971):

$$\Gamma\left(\tau^- \rightarrow (\text{hadrons})^- \nu_\tau\right) = \frac{G_F{}^2}{32\pi^2 m_\tau^3} \int_0^{m_\tau^2} dq^2 \left(m_\tau^2 - q^2\right)^2 \times \Big\{\{\cos^2\theta_C \left[\left(m_\tau^2 + 2q^2\right)\left(v_1\left(q^2\right) + a_1\left(q^2\right)\right) + m_\tau^2 a_o(q^2)\right]$$
$$+ \sin^2\theta_C \left[\left(m_\tau^2 + 2q^2\right)\left(v_1^s\left(q^2\right) + a_1^s\left(q^2\right)\right) + m_\tau^2\left(v_0^s\left(q^2\right) + a_0^s\left(q^2\right)\right)\right]\Big\} \qquad (1)$$

where, $v_1$, $a_1$ $v_0$ and $a_0$ are the spectral functions corresponding to the non-strange vector, axial-vector, scalar and pseudo-scalar final states, respectively and are functions of $q^2$, the invariant mass of hadronic final state and $\theta_c$ is the Cabibbo angle. $V^S{}_1$, $a^S{}_1$, $v^S{}_0$ and $a^S{}_0$ are the corresponding spectral functions for the strange final states. Each spectral function refers to final states having unique spin-parity and strangeness assignments. The spectral functions $v_1$, $a_1$ $v^S{}_1$ and $a^S{}_1$ is related to final states with J = 1, whereas, $a_0$, $v^S{}_0$ and $a^S{}_0$ comes from the final states with J = 0. $v_0$ is due to CVC.

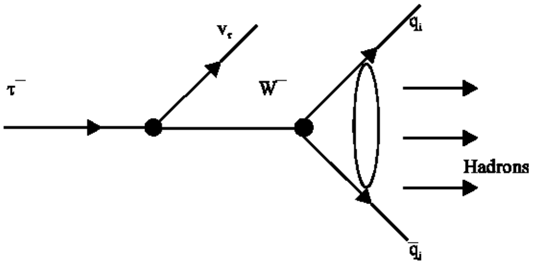

Fig. 1: Feynman diagram for hadronic tau decay ($\tau^-\rightarrow(\text{hadrons})^-V_\tau$)

## CALCULATE THE BRANCHING FRACTION FOR ONE PIONIC TAU DECAY

The most general form of the hadronic decay width has been given in Eq. 1. For any single particle final state this equation is reduced to the term containing the corresponding spectral function only and the spectral function is then described by the matrix element of the corresponding weak current between the vacuum state and given particle final state (Tsai, 1971). The corresponding spectral function for the decay $\tau^-\rightarrow\pi\nu_\tau$ is given by:

$$a_0\left(q^2\right)=2\pi f_\pi^2\delta\left(q^2-m_\pi^2\right) \tag{2}$$

Equation 1 and 2 gives:

$$\Gamma\left(\tau^-\rightarrow\pi^-\nu_\tau\right)=\frac{G^2f_\pi^2\cos^2\theta_C\, m_\tau^3}{16\pi}\left[1-\left(\frac{m_\pi}{m_\tau}\right)^2\right]^2 \tag{3}$$

The muonic tau decay width for pion is given by:

$$\Gamma\left(\pi^-\rightarrow\mu^-\bar{\nu}_\mu\right)=\frac{G^2f_\pi^2\cos^2\theta_C}{8\pi}m_\pi m_\mu^2\left[1-\left(\frac{m_\mu}{m_\pi}\right)^2\right]^2 \tag{4}$$

Equation 3 and 4 reduces to:

$$\Gamma\left(\tau^-\rightarrow\pi^-\nu_\tau\right)=\frac{m_\tau^3\left[1-\left(\frac{m_\pi}{m_\tau}\right)^2\right]^2}{2m_\pi m_\mu^2\left[1-\left(\frac{m_\mu}{m_\pi}\right)^2\right]^2}\Gamma\left(\pi^-\rightarrow\mu^-\bar{\nu}_\mu\right) \tag{5}$$

Therefore, the branching fraction of the pionic tau decay is determined by the pion and tau life times ($\tau_\pi$ and $\tau$):

$$\mathrm{Br}\left(\tau^-\rightarrow\pi^-\nu_\tau\right)=\frac{\Gamma\left(\tau^-\rightarrow\pi^-\nu_\tau\right)}{\Gamma_{tot}}=\tau_\tau\Gamma\left(\tau^-\rightarrow\pi^-\nu_\tau\right)=\frac{m_\tau^3\left[1-\left(\frac{m_\pi}{m_\tau}\right)^2\right]^2}{2m_\pi m_\mu^2\left[1-\left(\frac{m_\mu}{m_\pi}\right)^2\right]^2}\frac{\tau_\tau}{\tau_\pi}\mathrm{Br}\left(\pi^-\rightarrow\mu^-\bar{\nu}_\mu\right) \tag{6}$$

Table 2: Branching fraction for decay mode $\tau^- \rightarrow \pi^- v_\tau$

| Br (%) | References |
|---|---|
| 10.828±0.14 | Davier and Zheng (1997) |
| 11.09±0.15 | Heltsley (1995) |
| 11.06±0.18 | Buskulic (1995) |
| 10.91±0.07 | Amsler *et al.* (2008) |

Br: Branching ratio

Where:
Br: Branching ratio

By using the particle data group (Lyon, 2004) we obtain:

$$\mathrm{Br}\left(\tau^- \rightarrow \pi^- \nu_\tau\right) = (10.867 \pm 0.17)\% \tag{7}$$

This is in excellent agreement with experimental measurement shown in Table 2.

## CALCULATION OF THE BRANCHING FRACTION FOR ONE KAONIC TAU DECAY

The corresponding spectral function for kaonic tau decay is:

$$a_0^s\left(q^2\right) = 2\pi f_k^2\, \delta\left(q^2 - m_k^2\right) \tag{8}$$

The strength of the axial-vector current coupling to the kaon, is $f_k \sin \theta_c$ and is measured in kaon decay via $k^- \rightarrow {}^{--} + v_\tau$. As the same as pionic tau decay, we can derive kaonic tau decay branching fraction as:

$$\mathrm{Br}\left(\tau^- \rightarrow K^- \nu_\tau\right) = \frac{m_\tau^3\left[1-\left(\frac{m_K}{m_\tau}\right)^2\right]^2}{2 m_K m_\mu^2\left[1-\left(\frac{m_\mu}{m_K}\right)^2\right]^2} \frac{\tau_\tau}{\tau_K} \mathrm{Br}\left(K^- \rightarrow \mu^- \overline{\nu}_\mu\right) \tag{9}$$

From particle data group (Amsler *et al.*, 2008), we have obtained the branching fraction of kaonic tau decay as:

$$\mathrm{Br}\left(\tau^- \rightarrow K^- \nu_\tau\right) = (0.71 \pm 0.14)\%, \tag{10}$$

which is in excellent agreement with experimental data shown in Table 3. In another way we have:

$$\mathrm{Br}\left(\tau^- \rightarrow \pi^- \nu_\tau\right) + \mathrm{Br}\left(\tau^- \rightarrow K^- \nu_\tau\right) = \mathrm{Br}\left(\tau^- \rightarrow h^- \nu_\tau\right), \tag{11}$$

where, $h^-$ means $\pi^-$ or $k^-$. By using particle data group (Amsler *et al.*, 2008) and Eq. 11 the other value for the branching fraction of kaonic tau decay is obtained as:

$$\mathrm{Br}\left(\tau^- \rightarrow K^- \nu_\tau\right) = (0.73 \pm 0.06)\% \tag{12}$$

Table 3: Branching fraction for hadronic tau decay

| Br ($\tau^-\rightarrow K^-v_\tau$) (%) | Br ($\tau^-\rightarrow h^-v_\tau$) (%) | Experiment | References |
|---|---|---|---|
| (0.68±0.04) | (11.57±0.23) | ALEPH;DELPHI | Davier and Zheng (1997)<br>and Abdallah *et al.* (2006) |
| (0.696±0.03) | (11.70±1.00) | ALEPH | Barate (1999) |
| (0.72±0.06) | (11.90±0.99) | ALEPH;DELPHI | Abreu *et al.* (1991) |
| (0.695±0.23) | (11.60±0.06) | PDG(2008) | Amsler *et al.* (2008) |

Br: Branching ratio

## TAU DECAYS INTO VECTOR MESONS

A precise formulation of the weak hadronic decays depending only on the unknown spectral functions is represented by Eq. 1, so that each of which isolates particular hadronic channels. Eq. 1 represents a precise formulation of the weak hadronic decays depending only on the unknown spectral functions, each of which isolates particular hadronic channels. Specific relationships and predictions for these spectral functions can be obtained using CVC, PCAC and certain assumptions about the symmetries, as is usual in the phenomenology of weak hadronic decays. The CVC theorem relates the vector part of the strangeness conserving charged weak current to the isovector part of the total cross section for $e^-$ $e^+$ annihilations into hadrons:

$$v_1\left(q^2\right)=\frac{q^2\sigma_{I=1}\left(e^+e^-\rightarrow \text{hadrons}\right)}{4\pi^2\alpha^2}=\frac{\sigma_{I=1}\left(e^+e^-\rightarrow \text{hadrons}\right)}{3\pi\sigma_{pt}}, \tag{13}$$

where:

$$\sigma_{pl}=\frac{4\pi\alpha^2}{3q^2}$$

is the point cross section for the interaction $e^+$ $e^-\rightarrow\mu^+$ $\mu^-$. Therefore, CVC yields a definite prediction for the rate of tau decay into vector mesons.

## THE BRANCHING FRACTION OF TWO PIONIC TAU DECAY

The decay width of tau into vector mesons $\tau^-\rightarrow\rho^-v_\tau\rightarrow\pi^-\pi^\circ v_\tau$ (with G-parity equals 1), is obtained by considering the vector spectral function (Bisello *et al.*, 1989):

$$(q^2)=4\pi g_{\rho\gamma}^2\, m_\rho^2\,\delta(q^2-m_\rho^2)=2\pi\frac{f_\rho^2}{m_\rho^2}\delta(q^2-m_\rho^2)$$

where, $g^2_{\rho\gamma}$ = 1/8π, $g_{\rho\gamma}$ is the vector current coupling the ρ and the ρ decay constant, $f_\rho$, can be determined from the experimental data. From Eq. 1 and the vector spectral function we have:

$$\Gamma(\tau^-\rightarrow\rho^-\,v_\tau)=\frac{G_F^2\cos^2\theta_c\, m_\tau^6}{32\pi^4\, m_\tau^3}\left(1-\frac{m_\rho^2}{m_\tau^2}\right)^2\left(1+2\frac{q^2}{n_\tau^2}\right)\times 4\pi\left(\frac{1}{8\pi}\right)m_\rho^2 \tag{14}$$

Since:

$$\Gamma\left(\tau^-\rightarrow e^-\overline{v}_e v_\tau\right)=\frac{G_F^2 m_\tau^5}{192\pi^3}$$

Table 4: Branching fraction for decay $\tau^{-}\rightarrow\pi^{-}\pi^{0}\nu_{\tau}$

| Br ($\tau^{-}\rightarrow\pi^{-}\pi^{0}\nu_{\tau}$) (%) | References |
|---|---|
| (24.91±0.21) | Heltsley (1995) |
| (25.471±0.097±0.085) | Bacci *et al.* (1981) |
| (25.30±0.20) | Buskulic (1995) |
| (25.52±0.10) | Amsler *et al.* (2008) |

Br: Branching ratio

Eq. 14 reduces to:

$$\frac{\Gamma\left(\tau^{-}\rightarrow\rho^{-}\nu_{\tau}\right)}{\Gamma(\tau^{-}\rightarrow e^{-}\nu_{e}\nu_{\tau})}=\frac{192\pi^{3}}{m_{\tau}^{5}}\times\frac{m_{\tau}^{3}m_{\rho}^{2}\cos^{2}\theta_{c}}{64\pi^{2}}=(3\pi)\cos^{2}\theta_{c}\left(\frac{m_{\rho}}{m_{\tau}}\right)^{2}\left[1-\left(\frac{m_{\rho}}{m_{\tau}}\right)^{2}\right]^{2}\left[1+2\left(\frac{m_{\rho}}{m_{\tau}}\right)^{2}\right] \tag{15}$$

By considering the experimental data $m_{\rho}$ = 775.5 MeV and $m_{\tau}$ = 1776.84 MeV from Eq. 15 we have:

$$\frac{\Gamma\left(\tau^{-}\rightarrow\rho^{-}\nu_{\tau}\rightarrow\pi^{-}\pi^{0}\nu_{\tau}\right)}{\Gamma(\tau^{-}\rightarrow e^{-}\nu_{e}\nu_{\tau})}=1.54 \tag{16}$$

Therefore:

$$\mathrm{Br}\left(\tau^{-}\rightarrow\pi^{-}\pi^{0}\nu_{\tau}\right)=1.54\times\mathrm{Br}(\tau^{-}\rightarrow e^{-}\nu_{e}\nu_{\tau})=1.54\times(17.85\pm0.05)\%\approx(27.5\pm0.05)\% \tag{17}$$

Which is almost in agreement with experimental data shown in Table 4.

## THE BRANCHING FRACTION OF 4 PIONIC TAU DECAY

The phenomenology of the 4 pionic final state tau decay is entirely analogous to that for the tau decay into $\rho\nu_{\tau}$. Since the decay proceeds through the vector current, one can again relate the decay rate to an integral over the cross section for the $e^{+}e^{-}$ annihilation into 4 pions. However, there are two possibility for the final states of $e^{+}e^{-}$ annihilation, namely $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ and $\pi^{+}\pi^{+}\pi^{-}\pi^{-}$. As the same in $\tau$ decay, there are two channels namely, $\pi^{-}\pi^{0}\pi^{0}\pi^{0}\nu_{\tau}$ and $\pi^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau}$. The isospin constrains implies the following linear relations between the corresponding rates (Gilman and Rhie, 1985):

$$\sigma_{e^{+}e^{-}}^{I=1}\rightarrow\pi^{+}\pi^{-}\pi^{+}\pi^{-}=2\times\frac{4\pi\alpha^{2}}{q^{2}}v_{1,\pi-3\pi^{\circ}\nu_{\tau}}\quad\sigma_{e^{+}e^{-}}^{I=1}\rightarrow\pi^{+}\pi^{-}\pi^{+}\pi^{-}=2\times\frac{4\pi\alpha^{2}}{q^{2}}[v_{1,\pi-2\pi^{\circ}\nu_{\tau}}-v_{1,\pi-3\pi^{\circ}\nu_{\tau}}] \tag{18}$$

Therefore, the spectral functions for 4 pionic final states tau decay are:

$$v_{1,\pi^{-}3\pi^{0}\nu_{\tau}}=\frac{q^{2}}{4\pi\alpha^{2}}\frac{1}{2}\sigma_{e^{-}e^{+}\rightarrow2\pi^{+}2\pi^{-}}^{I=1}\quad v_{1,2\pi^{-}\pi^{+}\pi^{0}\nu_{\tau}}=\frac{q^{2}}{4\pi\alpha^{2}}\left[\sigma_{e^{-}e^{+}\rightarrow\pi^{+}\pi^{-}2\pi^{0}}^{I=1}+\frac{1}{2}\sigma_{e^{-}e^{+}\rightarrow2\pi^{+}2\pi^{-}}^{I=1}\right] \tag{19}$$

From Eq. 1 and 19 we have:

$$R_{\pi^{-}\pi^{+}\pi^{-}\pi^{0}}=\frac{\Gamma\left(\tau^{-}\rightarrow\pi^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau}\right)}{\Gamma\left(\tau^{-}\rightarrow e^{-}\overline{\nu}_{e}\nu_{\tau}\right)}=\frac{3\cos^{2}\theta_{C}}{2\pi\alpha^{2}m_{\tau}^{8}}\int_{0}^{m_{\tau}^{2}}q^{2}.dq^{2}\left(m_{\tau}^{2}-q^{2}\right)^{2}\left(m_{\tau}^{2}+2q^{2}\right)\left[\frac{1}{2}\sigma_{e^{-}e^{+}\rightarrow\pi^{+}\pi^{+}\pi^{-}\pi^{-}}+\sigma_{e^{-}e^{+}\rightarrow\pi^{+}\pi^{-}\pi^{0}\pi^{0}}\right] \tag{20}$$

Table 5: Branching fraction for tau decays into 4 pions

| Br ($\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$) (%) | Br ($\tau^- \to \pi^- 3\pi^0\nu_\tau$) (%) | References |
|---|---|---|
| (4.590±0.057±0.064) | (0.977±0.069±0.058) | Davier and Zheng (1997) |
| (4.61±0.06) | (1.04±0.07) | Amsler *et al.* (2008) |

Br: Branching ratio

$$R_{\pi^-\pi^0\pi^0\pi^0} = \frac{\Gamma\left(\tau^- \to \pi^-\pi^0\pi^0\pi^0\ \nu_\tau\right)}{\Gamma\left(\tau^- \to e^-\overline{\nu}_e\nu_\tau\right)} = \frac{3\cos^2\theta_C}{2\pi\alpha^2 m_\tau^8}\int_0^{m_\tau^2} q^2.dq^2\left(m_\tau^2 - q^2\right)^2\left(m_\tau^2 + 2q^2\right)\left[\frac{1}{2}\sigma_{e^-e^+\to\pi^+\pi^+\pi^-\pi^-}\right] \qquad (21)$$

By considering the experimental data of FRASCATI-ADONE, MEA (Esposito *et al.*, 1980) and SLAC-PEP2-BABAR (Aubert *et al.*, 2005) in center of mass energy $\sqrt{s} = q = m_\tau = 1.776\ \text{Gev}$ we have:

$$\sigma_{e^-e^+\to\pi^+\pi^+\pi^-\pi^-} = 10.7\text{nb} = 25.7\times10^{-6}\left(\text{Gev}\right)^{-2}$$

And by using the data group FRASCATI-ADONE, GAMMA-GAMMA 2 (Bacci *et al.*, 1981):

$$\sigma_{e^-e^+\to\pi^+\pi^-\pi^0\pi^0}\left(\sqrt{s} = q = m_\tau = 1.776\ \text{Gev}\right) = 22.1\ \text{nb} = 56.8\times10^{-6}\left(\text{Gev}\right)^{-2}$$

From Eq. 20 and 21 we obtain:

$$R_{\pi^-\pi^+\pi^-\pi^0} = \frac{\text{Br}\left(\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau\right)}{B_e} = \frac{3\cos^2\theta_C}{2\pi\alpha^2 m_\tau^8}\times\frac{3}{20}m_\tau^{10}\left(\frac{1}{2}\times25.7\times10^{-6} + 56.8\times10^{-6}\right) = 0.281 \qquad (22)$$

$$R_{\pi^-3\pi^0} = \frac{\text{Br}\left(\tau^- \to \pi^- 3\pi^0\nu_\tau\right)}{B_e} = \frac{3\cos^2\theta_C}{2\pi\alpha^2 m_\tau^8}\times\frac{3}{20}m_\tau^{10}\left(\frac{1}{2}\times25.7\times10^{-6}\right) = 0.052 \qquad (23)$$

Substituting electronic tau decay width in Eq. 22-23 leads to:

$$\begin{aligned} \text{Br}\left(\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau\right) &= \left(5.004 \pm 0.067\right)\% \\ \text{Br}\left(\tau^- \to \pi^- 3\pi^0\nu_\tau\right) &= \left(0.93 \pm 0.067\right)\% \end{aligned} \qquad (24)$$

Which is approximately in agreement with experimental data shown in Table 5.

## THE ESTIMATION OF THE BRANCHING RATIO FOR TAU DECAY INTO STRANGE PARTICLES

In the framework of standard model we have (Kuhn and Mirkes, 1992):

$$\text{Br}\left(\tau^- \to \left(\text{Strange}\right)^-\nu_\tau\right) \equiv \frac{\Gamma\left(\tau^- \to \left(\text{Strange}\right)^-\nu_\tau\right)}{\Gamma\left(\tau^- \to \left(\text{anything}\right)^-\nu_\tau\right)} \qquad (25)$$

There are four possibilities for the decay of the τ, two of these involves hadronic final states and two involve leptonic final states.

Since, quarks can mix in the standard model, a factor of $|V_{ud}|^2 \cong \cos^2 \theta_c \cong 0.05$ is introduced to accompany the hadronic current in the ud state and similarly a factor $|V_{ud}|^2 \cong \sin^2 \theta_c \cong 0.05$ is present for the us case, where, $|V_{ud}|$ and $|V_{us}|$ are absolute CKM elements and $\theta_c$ is the Cabibbo angle. For the leptonic current there is no mixing and so the equivalent factor is 1. A consequence of Eq. 1 and 25 is:

$$\mathrm{Br}(\tau^- \rightarrow (\mathrm{Strange})^- v_\tau) \cong \frac{3|V_{ud}|^2}{3|V_{ud}|^2 + 1 + 3|V_{us}|^2 + 1} \cong \frac{3}{5}\sin^2 \theta_c \cong 3\%(26) \tag{26}$$

The factor 3 in front of the $|V_{ij}|^2$, is correspond to the 3 possible quark colors.

## CONCLUSIONS

The CVC (Conserved Vector Current) theorem relates the vector part of the strangeness conserving charged weak current to the isovector part of the total cross section for $e^+ e^-$ annihilations into hadrons.

Conservation of angular momentum requires that the ensemble of final state hadrons produced in tau decays can only have total spin J = 0 or J = 1. In general, these final states should have either positive or negative parity. Therefore, the number of possible combinations of spin-parity and strangeness in the final state is restricted to 8 which in turn restricts the number of spectral functions we have needed to consider to obtain a complete description of the partial width of the tau decay to hadrons.

The relation between the cross sections and rates for producing the 4 pion combinations ($\pi^-$, $3\pi^0 v_\tau$, $2\pi^-\pi^+\pi^0\pi_\tau$, $2\pi^+\pi^-$, $\pi^+\pi^-2\pi^0$) in tau decays and $e^+ e^-$ annihilation gives important hints on the validity of isospin symmetry and the order of isospin breaking terms. The dependency of rates and cross sections on $\sqrt{Q^2}$, the invariant mass of the four-pion system and the differential mass distributions of 2 and 3 pions gives informations about the structures of amplitude resonance.

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