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DELPHI RESULTS ON THE HADRONIC DECAYS OF THE τ LEPTON

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ABSTRACT

The study of hadronic decays of the τ lepton provides important insights into the structure of hadronic currents and allows to make very stringent tests of theories of hadronic interactions.
At electron-positron colliders very clean events of the type $e^+e^- \to \tau^+\tau^-$ are an ideal laboratory to test the properties of the τ lepton.
Measurements of branching ratios of the τ into the main hadronic decay modes are presented, based on data collected in 1991 and 1992 with the DELPHI detector at LEP.
DELPHI results are compared with other experiments and with existing theoretical predictions.

1 INTRODUCTION

The coupling of the W boson to the charged current is universal: in a massless theory at tree level this implies that contributions to the τ decay width are such that $BR_l = BR(\tau^- \to \nu_\tau l^- \bar{\nu}_l) = 20\%$ where $l = e$ or μ and $R_\tau = BR(\tau^- \to \nu_\tau hadrons^-)/BR(\tau^- \to \nu_\tau l^- \bar{\nu}_l) = 3$.
The experimentally measured values of $BR_l = 17.86 \pm 0.11\%$ and $R_\tau = 3.60 \pm 0.03\%$ (1) are correctly predicted by the theory if one includes mass corrections and radiative QCD corrections (2) (even if some criticism has been recently raised about the possibility of applying QCD techniques at the τ mass scale (3)).
Interest for exclusive branching ratio measurements has raised a lot during the past ten years due to inconsistencies in some measurements which, if confirmed, could be interpreted as an evidence for physics beyond the Standard Model: universality of the weak couplings has been in trouble for a long time because of a disagreement between the directly measured $BR(\tau^- \to \nu_\tau e^- \bar{\nu}_e)$ and the one calculated from the Standard Model (with the measurements of τ lifetime and mass as inputs) whereas recent measurements give $g_\tau/g_\mu = 0.091 \pm 0.006$ (4) ; moreover, considering world averages, the measured inclusive one-prong topological branching ratio has also been for a long time significantly larger than the sum of the exclusive one-prong decays; again, the most recent and complete experimental analyses (4) see no evidence for this discrepancy.

2 HADRONIC DECAYS

The τ decays are an ideal laboratory to study *hadronic weak currents* in very clean conditions: final states are not plagued by interference effects which are present in hadronic production experiments, and, unlike $e^+e^- \to \gamma^* \to hadrons$ which only tests the *vector* current, the τ decays to hadrons test both the *vector* and the *axial* current. The hadronic charged current can be written as

$$J_h^{(i)\mu} = [J_V^{(i)\mu} - J_A^{(i)\mu}]cos\theta_c + [J_V^{(i,S)\mu} - J_A^{(i,S)\mu}]sin\theta_c \qquad (1)$$

where the index $(i), i = 0, 1$ refers to the total angular momentum of the final state and θ_c is the Cabibbo angle. The most important hadronic final states in τ decays are given in table 1 along with their relative quantum numbers: it is worth noting that the above currents do not interfere because the corresponding final states carry different quantum numbers.
Assuming pointlike interactions, the decay width can be expressed in terms of vector and axial spectral functions as

$$\Gamma(\tau^- \to \nu_\tau hadrons^-) = \frac{G_F^2}{(2\pi)^2(2m_\tau)^3} \int_0^{m_\tau^2} (m_\tau^2 - q^2) dq^2$$

	S	Q	J^P	examples
$J_V^{(0)}$	0	-1	1^-	$\rho^-, (2\pi)^-, (4\pi)^-$
$J_A^{(0)}$	0	-1	$0^-, 1^+$	$\pi^-, a_1^-, (3\pi)^-, (5\pi)^-$
$J_V^{(1)}$	-1	-1	$0^+, 1^-$	$K_0^{*-}(1430), K^{*-}$
$J_A^{(1)}$	-1	-1	$0^-, 1^+$	$K^-, K_1^-(1270), K_1^-(1400)$

TABLE 1: Allowed hadronic final states in τ decay (the decay into a state with S=0 and $J^P = 0^+$ is forbidden by CVC)

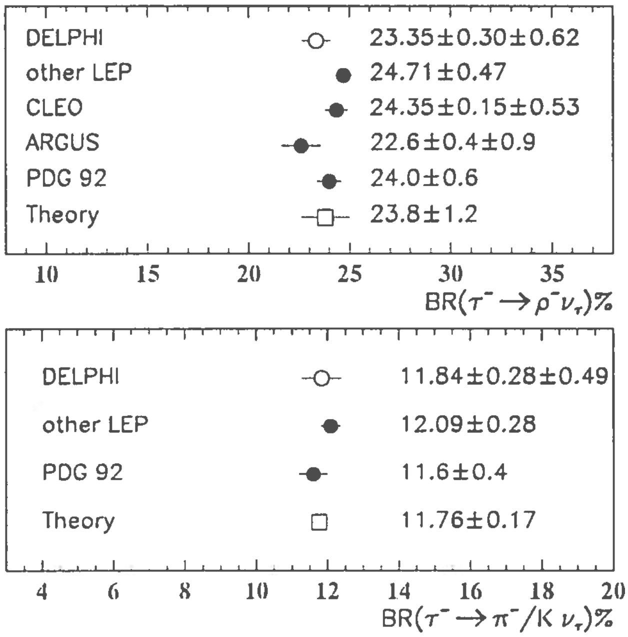

FIG. 1: *Branching fractions to* ρ *and to* π^-/K^-

$$\{[(m_\tau^2 + 2q^2)(v_1(q^2) + a_1(q^2)) + m_\tau^2(v_0(q^2) + a_0(q^2))]cos\theta_c$$
$$+[(m_\tau^2 + 2q^2)(v_1^S(q^2) + a_1^S(q^2)) + m_\tau^2(v_0^S(q^2) + a_0^S(q^2))]sin\theta_c\} \quad (2)$$

The various allowed final states will be now analysed in turn.

S=0 $J^P = 1^-$

The most abundant decay mode with these quantum numbers is $\tau^- \rightarrow \pi^-\pi^0\nu_\tau$ which is dominated by the resonance $\rho^-(770)$ (the non resonant part of the amplitude has been measured by CELLO [9] and found to be $(0.3 \pm 0.1 \pm 0.1)\%$).

Assuming Conserved Vector Current hypotesis [7] , an estimate of the corresponding form factor can be obtained from measurements of the isovector part of the cross section

	$BR(\tau^- \to K^- \nu_\tau)(\%)$
DELPHI	0.93 ± 0.20
PDG	0.67 ± 0.23
theory	0.73 ± 0.07

TABLE 3: Branching fractions to K^-

	$BR(\tau^- \to K^{*-} \nu_\tau)(\%)$
DELPHI (from $K^{*-} \to \pi^0 K^-$)	1.71 ± 0.63
PDG (from $K^{*-} \to \pi^- K^0_S$)	1.39 ± 0.20
theory	≈ 1.74

TABLE 4: Branching fractions to K^{*-}

S=1 $J^P = 0^-$
The dominant final state is $\tau^- \to K^- \nu_\tau$: the theoretical prediction is obtained, in analogy to $\tau^- \to \pi^- \nu_\tau$, from $K^- \to \mu^- \bar{\nu_\mu}$.
On the experimental side, it is often measured $BR(\tau^- \to K^-/\pi^- \nu_\tau)$ without trying to distinguish between K and π (see fig 1) or one can try to identify the K to measure $BR(\tau^- \to K^- \nu_\tau)$ alone.
To measure the latter branching fraction, DELPHI used the barrel Ring Imaging Cherenkov [15] ; this detector includes a liquid radiator and a gaseous one: due to the large average momentum of the K in the τ decay, only the gas radiator has been utilized.
Two methods have been deviced depending on the momentum of the decaying K:

- 3.5-9 GeV/c : the detector is used in veto mode, because in this momentum range pions give light but kaons do not.
- 9-30 GeV/c : the kaon identification is achieved through recostruction of rings of emitted Cherenkov light.

Table 3 compares experimental results (from [1, 5]) with the theoretical prediction.
S=1 $J^P = 1^+$
The main decay mode is $\tau^- \to K^{*-} \nu_\tau$ with the subsequent decay $K^{*-} \to K\pi$.
Assuming exact $SU(3)$ flavour symmetry one has:

$$R^0_{K^*} = \frac{BR(\tau^- \to K^{*-} \nu_\tau)}{BR(\tau^- \to \rho^- \nu_\tau)} = tan^2\theta_c \cdot f(m_\tau, m_{K^*}, m_\rho) \qquad (3)$$

$SU(3)$ symmetry breaking can be incorporated using *Das-Matsur-Okubo* sum rule [16] , giving a 35% correction to the naive expectation (3).

model	experiment	$m_{a_1}(GeV)$	$\Gamma_{a_1}(GeV)$
I-M-R	ARGUS	1.211 ± 0.007	0.446 ± 0.021
K-S	ARGUS	1.274 ± 0.007	0.594 ± 0.023
	DELPHI	1.270 ± 0.015	0.604 ± 0.050

TABLE 2: a_1 mass and width determinations

$e^+e^- \rightarrow \pi^+\pi^-$.
Fig 1 shows measurements of $BR(\tau^- \rightarrow \rho^-\nu_\tau)$ from various experiments ([1, 6, 4, 5]) along with the prediction from CVC.
S=0 $J^P = 0^-$
For the decays which involve the axial current, only a partial conservation law can be exploited, implying $a_0(q^2) = 0$ for $q^2 > m_\pi^2$: this means that the only decay mode with these quantum numbers is $\tau^- \rightarrow \pi^-\nu_\tau$.
A prediction for this decay rate is obtained from the decay $\pi^- \rightarrow \mu^-\nu_\mu$, which is described by the same hadronic matrix element.
S=0 $J^P = 1^+$
In the decays $\tau^- \rightarrow \pi^-\pi^-\pi^+\nu_\tau$ and $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$ a clear dominance of the resonance $a_1^-(J^P = 1^+) \rightarrow \rho\pi$ is seen (an upper limit on the branching ratio to non-resonant modes has been put by ARGUS [8]).
From isospin considerations, the branching ratios into the two decay modes are foreseen to be equal (small differences are expected from phase space effects).
For the description of the hadronic part of the decay a few models are available such as the *Kühn-Santamaria*'s [10] based on chiral dynamics and the *Isgur-Morningstar-Reader*'s [11] based on flux-tube breaking model.
These models give predictions on the branching ratio which depend on a_1 resonance parameters: for instance in the K-S model by varying the mass between 1200 and 1300 MeV and the width between 550 and 650 MeV one gets a maximum absolute variation on the branching ratio of about 1% [12] ; unfortunately the extraction of the above parameters from the experimental data is model dependent as well, as shown in table 2(see [4, 12]).
In the future, with more statistics coming, it will be possible to distinguish among various models through a_1 decay products angular distributions [14] .
As far as measurements of branching fractions are concerned, large discrepancies are observed among various experiments both for the charged and the neutral decay modes: in fig 2 only more recent and precise measurement (from [4, 12]) are shown and compared with a prediction from the K-S model [12] obtained from a fit to data from the DELPHI experiment [13] .

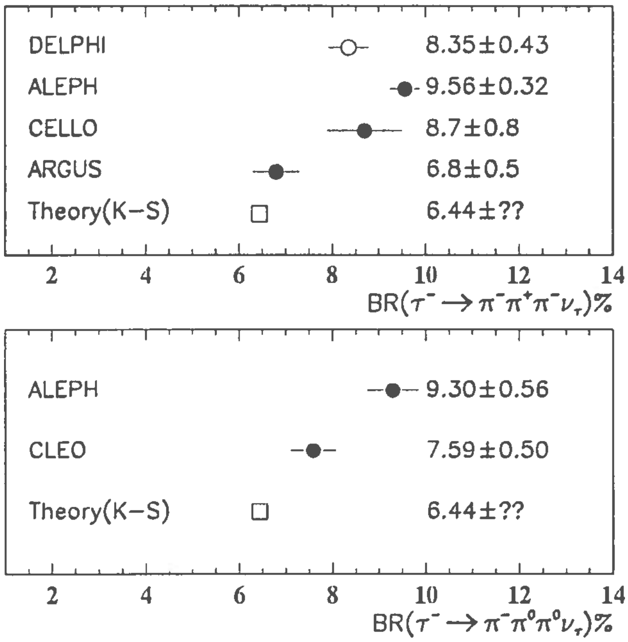

FIG. 2: *Branching fractions to three pions.*

Table 4 shows a comparison of experimental results (from [1, 5]) with the theoretical prediction of [16].

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