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SEARCHES FOR NEW PARTICLES AT A TAU-CHARM FACTORY*

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ABSTRACT

This paper outlines the potential for new particle searches in tau and charm physics at a Tau-Charm Factory.

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A. Introduction

The tau-charm factory consists of a high luminosity, two-ring, electron-positron collider and a detector with the following properties:

- Range of total energy = 3.0 to 5.0 GeV
- Design luminosity $\geq 10^{33}$ cm^{-2} s^{-1}
- High resolution, large acceptance detector specially designed for tau and charm physics

There is now an extensive literature on the design and physics potential of a tau-charm factory. The original descriptions are by Kirkby (1987, 1989) and Jowett (1987, 1988, 1989). Two international workshops have been devoted to the tau-charm factory Beers (1989), Kirkby and Quesada (1992). Studies of the design of the collider have been done by Brown *et al.* (1989), Gonichon *et al.* (1990), Barish *et al.* (1990), Danilov *et al.* (1990) and Baconnier *et al.* (1990). Papers on the physics and on detector designs include Schindler (1989, 1990a, 1990b), Perl (1991), Pich (1991), Wermes (1992), and Davier (1991). A recent review of the concept and potential physics of a tau-charm factory has been written by Kirkby and Rubio (1992).

In research at a tau-charm factory the experimenters will be able to carry out precise and probing studies of tau and charm physics through the use of the four basic elements of the tau-charm factory concept:

- Control of and direct measurement of backgrounds and contaminations.
- Very large statistics.
- Production of particles in known quantum mechanical states.
- Detector with very high quality particle identification, very good momentum and energy resolution, and close to 4π acceptance.

In experiments at the tau-charm factory the particles are produced at resonances or at energies just above production thresholds, Fig. 1.:

$$\begin{aligned}
&\text{Tau Pair :} && e^+ + e^- \rightarrow \tau^+ + \tau^- && (1a)\\
&\text{Charmed meson :} && e^+ + e^- \rightarrow D^+ + D^-, \quad \text{at } \Psi'' && \\
& && e^+ + e^- \rightarrow D^0 + \bar{D}^0, \quad \text{at } \Psi'' && (1b)\\
& && e^+ + e^- \rightarrow D^0 + \bar{D}^{*0} && \\
& && e^+ + e^- \rightarrow D_s^+ + D_s^- && \\
&\text{Charmed baryon:} && e^+ + e^- \rightarrow \Lambda_c + \bar{\Lambda}_c && (1c)\\
&\text{Charmonium:} && e^+ + e^- \rightarrow J/\Psi && (1d)\\
& && e^+ + e^- \rightarrow \Psi' &&
\end{aligned}$$

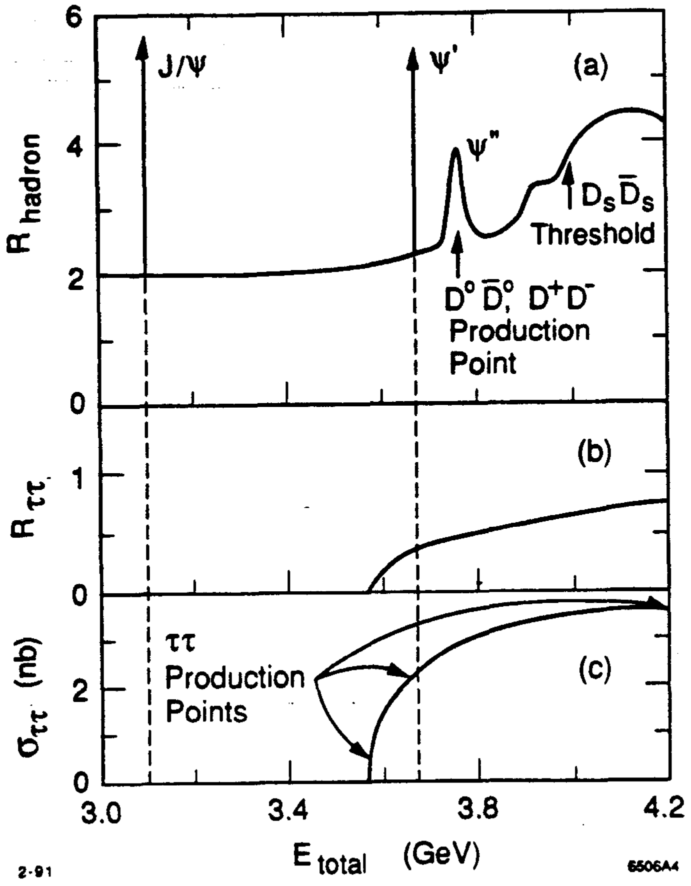


Figure 1.

For example, the primary operating energies for τ pair production are:

$$\begin{aligned} &3.57 \text{ GeV: just above the } \tau \text{ threshold} \\ &3.67 \text{ GeV: just below the } \Psi' \text{ threshold} \end{aligned} \tag{2}$$

At these energies there is no production of charm or bottom hadrons, the only background is from ordinary hadrons, and that background is almost constant between these operating energies and the energy just below τ pair threshold. Gomez-Cadenas *et al.* (1989) have discussed the value of studying some areas of τ physics just above the τ pair threshold where the produced τ's are almost at rest.

Table 1 gives the rates for particle production at the tau-charm factory.

Table 1. Particle production rates at the tau-charm factory year, based on 10 fb^{-1} per year*.

Particle	Events per year
D^0 (single)	5.8×10^7 at Ψ''
D^+ (single)	4.2×10^7 at Ψ''
D_s (single)	1.8×10^7 at 4.24 GeV
$\tau^+\tau^-$ (pairs)	0.5×10^7 at 3.57 GeV
$\tau^+\tau^-$ (pairs)	2.4×10^7 at 3.67 GeV
$\tau^+\tau^-$ (pairs)	3.5×10^7 at 4.25 GeV
J/Ψ (events)	1.7×10^{10}
Ψ' (events)	0.4×10^{10}

*Based on L = 10^{33} cm^{-2} s^{-1} for 10^7 s/year. As machine operation matures, the collider will operate for 2×10^7 s/year.

There are two basic principles in the new particle searches to be made at a tau-charm factory:

- The total energy and the particle masses are relatively small, therefore only relatively small mass new particles can be produced and directly detected.
- Precise studies of tau lepton and charm particle decays, or detection of unconventional decays, can lead to the indirect discovery of new particles. The new particle might occur as a virtual particle in an intermediate state in the decay process. Or, an unexplained property of a decay mode or set of decay modes might reveal the presence of a new particle coupled to the known particles in the decay.

B. Searches in Tau Physics

There are four powerful advantages in studying the physics of the tau lepton and tau neutrino at the tau-charm factory:

- The availability of large data sets collected over short times.
- The selection of a τ pair data sample by single-tagging of events. That is, only one τ decay need be identified in order to select the event.
- There are no backgrounds from D or B meson decays.

- The backgrounds from non-τ pair events are directly measured by moving below the τ pair threshold.

B.1 Unconventional τ Decays to Known Particles

Unconventional τ decays to known particles in general require violation of both τ lepton number conservation and e or μ lepton number conservation. Examples are

$$\begin{aligned} \tau^- &\rightarrow e^- + \gamma \\ \tau^- &\rightarrow \mu^- + \gamma \\ \tau^- &\rightarrow e^- + \pi^0 \\ \tau^- &\rightarrow e^- + e^+ + e^- \end{aligned} \tag{3}$$

If a proton or neutron is allowed in the decay then only τ lepton number conservation needs to be violated:

$$\tau^- \rightarrow \bar{p} + \pi^0 \tag{4}$$

Figure 2 shows two possibilities for how an unknown intermediate particle might lead to the type of unconventional τ decays in Eq. 3.

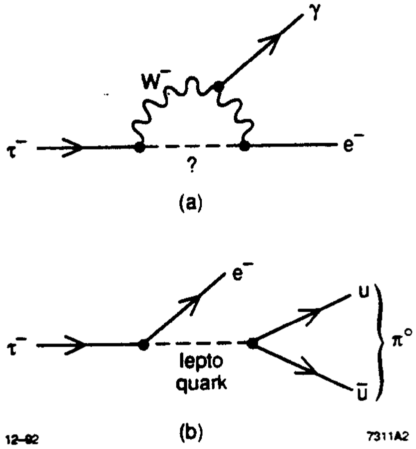


Figure 2.

It is relatively easy to look for such unconventional decays because all the particles in the final state can be detected and hence the mass of the τ can be reconstructed. If an experiment has n produced τ pairs whose unconventional decays can be detected, and if no unconventional decays are detected, then upper limits on the branching ratios of roughly

$$B\ (\text{unconventional decay}) \lesssim \text{few}/\text{n} \tag{5}$$

will be set. Thus Albrecht *et al.* (1992) using about 10^5 τ pairs have set the upper limits in Table 2. The CLEO II experimenters with about 10^6 τ pairs have recently set the limit (Barish, 1992)

$$B(\tau^- \to e^-\gamma) < 4.2 \times 10^{-6} \tag{6}$$

Table 2. Upper limits on unconventional branching fractions from Albrecht *et al.* (1992).

		Upper Limits $[10^{-5}]$ (90% CL)				
Nr.	decay channel	MARK II	ARGUS 86	Crystal Ball	CLEO	ARGUS 91
1.	$\tau^- \to e^-e^+e^-$	40	3.8		2.7	1.3
2.	$\tau^- \to e^-\mu^+\mu^-$	33	3.3		2.7	1.9
3.	$\tau^- \to e^+\mu^-\mu^-$				1.6	1.8
4.	$\tau^- \to \mu^-e^+e^-$	44	3.3		2.7	1.4
5.	$\tau^- \to \mu^+e^-e^-$				1.6	1.4
6.	$\tau^- \to \mu^-\mu^+\mu^-$	49	2.9		1.7	1.9
7.	$\tau^- \to e^-\pi^+\pi^-$		4.2		6.0	2.7
8.	$\tau^- \to e^+\pi^-\pi^-$				1.7	1.8
9.	$\tau^- \to \mu^-\pi^+\pi^-$		4.0		3.9	3.6
10.	$\tau^- \to \mu^+\pi^-\pi^-$				3.9	6.3
11.	$\tau^- \to e^-\rho^0$	37	3.9			1.9
12.	$\tau^- \to \mu^-\rho^0$	44	3.8			2.9
13.	$\tau^- \to e^-\pi^+K^-$		4.2		5.8	2.9
14.	$\tau^- \to e^+\pi^-K^-$				4.9	2.0
15.	$\tau^- \to \mu^-\pi^+K^-$		12		7.7	11
16.	$\tau^- \to \mu^+\pi^-K^-$				4.0	5.8
17.	$\tau^- \to e^-K^{*0}$	130	5.4			3.8
18.	$\tau^- \to \mu^-K^{*0}$	100	5.9			4.5
19.	$\tau^- \to e^-\gamma$	64		20		12
20.	$\tau^- \to e^-\pi^0$	210		14		17
21.	$\tau^- \to \mu^-\gamma$	55				3.4
22.	$\tau^- \to \mu^-\pi^0$	82				4.4
23.	$\tau^- \to e^-\eta$			24		6.3
24.	$\tau^- \to \mu^-\eta$					7.3
25.	$\tau^- \to \bar{p}\gamma$					29.0
26.	$\tau^- \to \bar{p}\pi^0$					65.5
27.	$\tau^- \to \pi^-\gamma$					28
28.	$\tau^- \to \pi^-\pi^0$					37
29.	$\tau^- \to \bar{p}\eta$					129

The tau-charm factory experiment will have about 10^8 τ pairs and thus can look for unconventional decays of the types in Eqs. 3 and 4 with branching ratios as small as few $\times 10^{-8}$ The use of a tau-charm factory is necessary not only to achieve sample sizes of 10^8 τ pairs but also to carry out the precise measurements which are necessary to eliminate backgrounds. For example, the unconventional decays

$$\begin{aligned} \tau^- &\rightarrow e^- + e^+ + e^- \\ \tau^- &\rightarrow \mu^- + e^+ + e^- \end{aligned} \tag{7a}$$

can be faked by the conventional decays

$$\begin{aligned} \tau^- &\rightarrow e^- + \bar{\nu}_e + \nu_\tau + e^+ + e^- \\ \tau^- &\rightarrow \mu^- + \bar{\nu}_\mu + \nu_\tau + e^+ + e^- \end{aligned} \tag{7b}$$

if the total momentum of the neutrinos is close to zero.

Masiero (1991) has reviewed theories which can lead to the unconventional decays discussed in this section.

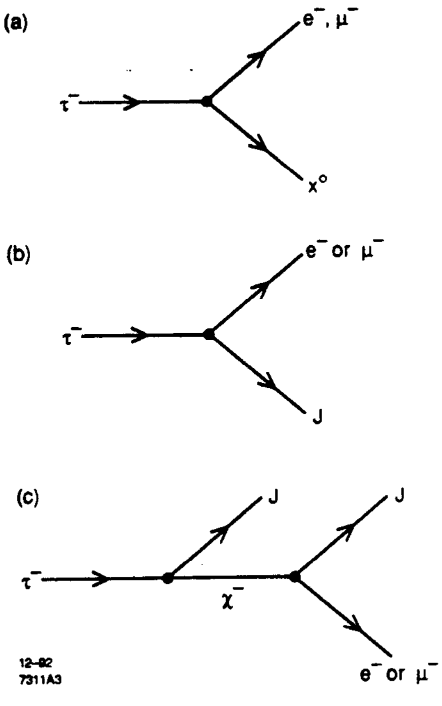


Figure 3.

B.2 Unconventional τ Decays to Unknown Particles

It is much more difficult to look for unconventional τ decays with an unknown, *weakly interacting* particle, x^0, in the final state. Examples are:

$$\begin{aligned} \tau^- &\rightarrow e^- + x^0 \\ \tau^- &\rightarrow \mu^- + x^0 \\ \tau^- &\rightarrow e^- + \text{hadrons} + x^0 \end{aligned} \tag{8}$$

as shown in Fig. 3a. Since the x^0 has only weak interactions it will not be detected.

The only search so far made for such unconventional decays was by Baltrusaitis *et al.* (1985) looking for a light Goldstone boson in

$$\begin{aligned} \tau^- &\rightarrow e^- + G \\ \tau^- &\rightarrow \mu^- + G \end{aligned} \tag{9}$$

They set the 95% confidence level upper limits

$$\begin{aligned} B(\tau \rightarrow e\,G)/B(\tau \rightarrow e\nu\nu) &< 4.0\% \\ B(\tau \rightarrow \mu G)/B(\tau \rightarrow \mu\nu\nu) &< 12.0\% \end{aligned} \tag{10}$$

There are two difficulties in finding modes such as those in Eq. 8, or even in setting small upper limits on the branching fractions. First, the τ mass cannot be reconstructed because the x^0 cannot be detected. Second, there are severe background problems. For example, the backgrounds to the decay

$$\tau^- \rightarrow e^- + x^0 \tag{11a}$$

are

$$\tau^- \rightarrow \pi^- + \nu_\tau \tag{11b}$$

with the π misidentified as an e, and

$$\tau^- \rightarrow e^- + \bar{\nu}_e + \nu_\tau \tag{11c}$$

Indeed the decay in Eq. 11c always provides some background because the two neutrinos can always be reinterpreted as a particle of mass

$$m = \left[(E_\tau - E_e)^2 - (\vec{p}_\tau - \vec{p}_e)^2 \right]^{\frac{1}{2}} \tag{12}$$

In a tau-charm factory experiment the uncertainty in m can be reduced by using data acquired near threshold, hence the significance of this background can be reduced.

Romão *et al.* (1991) have discussed a theoretical example of a τ decay of the type in Eq. 8.

$$\tau^- \to e^- \text{ or } \mu^- + J \tag{13}$$

where J is a majoron. They also discuss

$$\tau^- \to e^- \text{ or } \mu^- + J + J \tag{14}$$

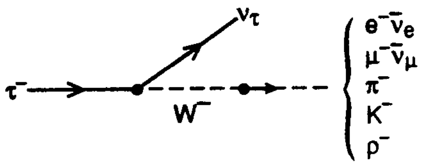
B.3 Searches Using Precise Measurements of Calculable τ Decays

The decay widths, Γ_i, for five decay modes can be calculated from weak interaction theory and non$-\tau$ measurement (Perl 1992a) as outlined here:

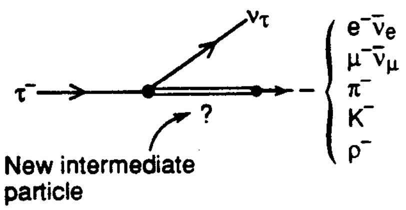
$$\begin{array}{r}\tau^- \to \nu_\tau + e^- + \bar{\nu}_e \longleftarrow \\ \tau^- \to \nu_\tau + \mu^- + \bar{\nu}_\mu \longleftarrow\end{array}\left[\begin{array}{l}\text{use weak interaction}\\ \text{theory}\end{array}\right. \tag{15a}$$

$$\begin{array}{r}\tau^- \to \nu_\tau + \pi^- \longleftarrow \\ \\ \tau^- \to \nu_\tau + K^- \longleftarrow\end{array}\left[\begin{array}{l}\text{use weak interaction theory}\\ \text{theory and}\\ \pi^- \to \mu^-\bar{\nu}_\mu,\ K^- \to \mu^-\bar{\nu}_\mu \text{ widths}\end{array}\right. \tag{15b}$$

$$\tau^- \to \nu_\tau + \rho^- \longleftarrow \left[\begin{array}{l}\text{use weak interaction}\\ \text{theory and}\\ e^+e^- \to \rho^0 \text{ cross section}\end{array}\right. \tag{15c}$$



(a) Standard decay process



(b) Unconventional decay process

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Figure 4.

As shown schematically in Fig. 4b, an unconventional decay process could occur through an unknown intermediate particle, and this would interfere with the conventional decay process in Fig. 4a. This could change the decay widths, or in the case of three body decay modes, the kinematic distributions could be altered.

Table 3 gives recent average values of the five decay modes in Eq. 15. For the first four modes the fraction errors in the branching ratios are in the range

$$1\% \lesssim \frac{\sigma_B}{B} \lesssim 3\% \tag{16}$$

(The $\tau^- \to K^- \nu_\tau$ mode has a much larger fractional error in B.) But the errors in Table 3 and in Eq. 16 may be underestimated. The errors depend upon the conventional but murky process of adding statistical and systematic errors in quadrature (Hayes and Perl 1988). In addition, the average values in Table 3 are obtained by averaging over many measurements, a calculation which has other uncertainties.

Table 3. Branching fractions for some decay modes whose decay widths can be calculated from weak interaction theory and non$-\tau$ measurements. The first four branching fractions are taken from or deduced from Galik (1992), the fifth is from Aguilar-Benitez *et al.* (1992).

Mode	Branching Fraction in %
$\nu_\tau e^- \bar{\nu}_e$	17.75 ± 0.15
$\nu_\tau \mu^- \bar{\nu}_\mu$	17.39 ± 0.17
$\nu_\tau \pi^-$	11.73 ± 0.35
$\nu_\tau \rho^-$	24.29 ± 0.24
$\nu_\tau k^-$	0.67 ± 0.23

But even if we take these errors as given, the comparison of branching fraction measurements with the calculation outlined in Eq. 15 has yet a larger error. We must compare the ratios

$$B_i/B_j = \Gamma_i/\Gamma_j \tag{17}$$

For example, weak interaction theory predicts (Perl 1992a)

$$(B_\mu/B_e)_{theory} = 0.973 \tag{18a}$$

and from Table 3

$$(B_\mu/B_e)_{measured} = 0.980 \pm 0.013 \tag{18b}$$

Thus the measured ratio has a fractional error of about 1.3%, but from the discussion in the last paragraph we might prefer assigning a 2% or 3% error.

Substantial reduction of these errors to say 0.1%, including more certainty about the systematic error, requires a single experiment with very high statistics and direct knowledge of backgrounds. This can only be achieved at a tau-charm factory.

B.4 Comparison of τ Lifetime with Leptonic Decays

From the first years of τ research in the 1970's it has been recognized that the τ lifetime, T_τ, is predicted by (Perl 1992a)

$$T_\tau = \frac{\hbar B(\tau^- \to \nu_\tau \ell^- \bar{\nu}_\ell)}{\Gamma(\tau^- \to \nu_\tau \ell^- \bar{\nu}_\ell)} \quad ; \ell = e \text{ or} \tag{19a}$$

$$\Gamma(\tau^- \to \nu_\tau \ell^- \bar{\nu}_\ell) = \frac{G_F^2 m_\tau^5}{192\pi^3} F_\ell(y) F_W F_{rad} \tag{19b}$$

$$F_\ell(y) = 1 - 8y + 8y^3 - y^4 - 12y^2 lny \tag{19c}$$

where

$$y = m_\ell^2/m_\tau^2 \quad ;$$

and

$$F_W = 1.0003$$

is the correction for finite W mass and

$$F_{rad} = 0.9957$$

is the radiative correction.

Also, since the first measurements of T_τ seemed to be larger than the T_τ predicted by Eqs. 19 and measured values of B_e and B_μ, there has been speculation that (a) a second neutrino, N_τ, couples to the τ and (b) the mass of N_τ is larger than m_τ

$$m_{N_\tau} > m_\tau \tag{20}$$

Then the $\tau - W - \nu_\tau$ coupling would be given by

$$g_{\tau W \nu_\tau} = \cos\theta_\tau g_{eW\nu_e} \tag{21}$$

and the τ lifetime would be increased by $(\cos\theta_\tau)^{-2}$. A recent discussion has been given by Ma *et al.* (1992).

Thus if T_τ (measured) were larger than T_τ (calculated) from Eqs. 19 and measured values of B_e and B_μ, there would be evidence for new physics. That new physics might consist of a new particle N_τ. Or, the new physics might be that $e - \mu - \tau$ universality is violated, the $\tau W \nu_\tau$ coupling being different from the $e W \nu_e$ and $\mu W \nu_\mu$ couplings.

At present the experimental situation is as follows. From B_e and B_μ in Table 3 we predict

$$T_\tau \text{ (calculated from } B_e) = 288.8 \pm 2.4 \text{ fs} \tag{22a}$$

$$T_\tau \text{ (calculated from } B_\mu) = 290.9 \pm 2.8 \text{ fs} \tag{22b}$$

These calculations are not independent because some measured values of B_e and B_μ are correlated. Here I use the evaluation of Trischuk (1992) for

$$T_T(\text{measured}) = 295.7 \pm 3.2 \text{ fs} \tag{23}$$

Comparing Eq. 22a with Eq. 23, T_τ (measured) agrees with T_τ (calculated) to within 1.7 standard deviations with the former longer. Using Eq. 22b gives a similar result. At present we cannot claim that there is a discrepancy which requires new physics for an explanation. As I said in Perl, (1992a) it will take more precise measurements if B_e, B_μ and T_τ to decide whether or not there is a disengaging. The tau-charm factory will permit much more precise measurements of B_e and B_μ. The most difficult problem for future comparisons is how to substantially improve the precision of T_τ.

B.5 Summation Issues in τ Decays

Since the work of Gilman and Rhie (1985) and Truong (1984) the world of τ research has been faced with the question: Can we find and identify all the decay modes of the τ with branching fractions

$$B_i \gtrsim \text{ few } \times 0.1\% \tag{24a}$$

such that

$$\sum_i B_i = 100\% \quad ? \tag{24b}$$

On the face of it Eq. 24b is an identify; the fundamental question is: Are there some unknown and unconventional τ decays such that

$$\sum_i B_i \text{ (known and measured)} < 100\% \text{ ?} \tag{24c}$$

Historically (Perl 1992a) the question was first asked about decay modes with 1-charged particle, B_{1i}, since these made up most τ decays. The topological 1 and 3-charged particle branching fractions according to the Particle Data Group

(Aguilar-Benitez *et al.* 1992) are

$$\begin{aligned} B_1 &= (85.52 \pm 0.25)\% \\ B_3 &= (14.06 \pm 0.25)\% \quad ; \end{aligned} \tag{25a}$$

and in a more recent computation by Galik (1992)

$$\begin{aligned} B_1 &= (85.26 \pm 0.18)\% \\ B_3 &= (14.63 \pm 0.18)\% \quad ; \end{aligned} \tag{25b}$$

We usually break up the question in Eq. 24c into two questions. Does

$$\sum_i B_{1i} \text{ (known and measured) } = B_1 \tag{26a}$$

and does

$$\sum_i B_{3i} \text{ (known and measured) } = B_3 \tag{26b}$$

Some kinds of searches for new particles in τ physics are intimately related to these questions. If a τ decay mode contains a new particle, that mode might not be found. Or even if a τ decay mode contains known particles, it might be unconventional and not recognized. I'll give an example of such speculations later in this section, first I turn to the data.

In the past few years most of the new measurements on τ branching fractions have come from experiments at the CESR and DORIS II e^+e^- colliders with $E_{tot} \sim$ 10 GeV and from the four experiments at the LEP collider with $E_{tot} \sim 92$ GeV. In general, these experiments cannot distinguish $\pi^\pm$ from $K^\pm$, and hence cannot distinguish

$$\tau^- \rightarrow \nu_\tau + \pi^- + n\pi^0 \ , \ n \geq 0 \tag{27a}$$

from

$$\tau^- \rightarrow \nu_\tau + K^- + n\pi^0 \ , \ n \geq 0 \tag{27b}$$

Therefore, the two decay modes are measured as one with the designation.

$$\tau^- \rightarrow \nu_\tau + h^- + n\pi^0 \ , \ n \geq 0 \tag{27c}$$

A similar problem occurs with 3-charged particle. For approximate measurements the adding of the π and K modes is not important since

$$\frac{B(\tau^- \to \nu_\tau K^- n\pi^0)}{B\tau^- \to \nu_\tau \pi^- n\pi^0)} \sim 5\% \tag{28}$$

But the separation of the π and K modes is important for precise measurements of the separate modes, for understanding the physics of the K decay modes, and for the precise exploration of the summation questions in Eqs. 26.

Precise separation of the π and K modes requires production of τ pairs at low energy and a specially designed detector. The tau-charm factory is the ideal instrument.

Table 4. World average values of τ branching fractions in % from Aguilar-Benitez *et al.* (1992).

Decay Mode	B(%)
$e^- \bar{\nu}_e \nu_\tau$	17.85 ± 0.29
$\mu^- \bar{\nu}_\mu \nu_\tau$	17.45 ± 0.27
$h^- \nu_\tau$	12.47 ± 0.35
$h^- \pi^0 \nu_\tau$	23.4 ± 0.6
$h^- 2\pi^0 \nu_\tau$	9.0 ± 0.6
$h^- \geq 3\pi^0 \nu_\tau$	1.8 ± 0.6
$\sum_i B_{1i}$	82.0 ± 1.2
B_1	85.94 ± 0.23
$\Delta_1 = B_1 - \sum_i B_{1i}$	3.9 ± 1.2
$2h^- h^+ \nu_\tau$	8.0 ± 0.3
$2h^- h^+ \geq 1\pi^0 \nu_\tau$	5.2 ± 0.4
$\sum_i B_{3i}$	13.2 ± 0.5
B_3	14.06 ± 0.20
$\Delta_3 = B_3 - \sum_i B_{3i}$	0.9 ± 0.5
B_5	0.11 ± 0.03
$\sum_i B_i$	95.3 ± 1.3

Table 5. World average values of τ branching fractions in % from Galik (1992).

Decay Mode	B(%)
$e^- \bar{\nu}_e \nu_\tau$	17.75 ± 0.15
$\mu^- \bar{\nu}_\mu \nu_\tau$	17.39 ± 0.17
$h^- \nu_\tau$	12.40 ± 0.26
$h^- \pi^0 \nu_\tau$	24.29 ± 0.24
$h^- 2\pi^0 \nu_\tau$	8.76 ± 0.33
$h^- \geq 3\pi^0 \nu_\tau$	$1.26 \pm \pm 0.13$
$\pi^- \pi^0 \eta \nu_\tau$	0.08 ± 0.03
$\sum_i B_{1i}$	81.93 ± 0.55
B_1	85.26 ± 0.18
$\Delta_1 = B_1 - \sum_i B_{1i}$	3.3 ± 0.6
$2h^- h^+ \nu_\tau$	8.62 ± 0.19
$2h^- h^+ \geq 1\pi^0 \nu_\tau$	5.45 ± 0.22
$\sum_i B_{3i}$	14.07 ± 0.29
B_3	14.63 ± 0.18
$\Delta_3 = B_3 - \sum_i B_{3i}$	0.6 ± 0.3
B_5	0.13 ± 0.03
$\sum_i B_i$	96.13 ± 0.62

Turning to the data, Tables 4 and 5 show two recent compilations from the Particle Data Group (Aguilar-Benitez *et al.* 1992) and from Galik (1992). Table 5 contains very recent data from the LEP experiments and from the CLEO II experiment as well as much of the data used in Table 4. The numbers in the tables are averages of measurements from several or even many experiments. To try to answer the questions in Eqs. 26 I give

$$\Delta_1 = B_1 - \sum B_{1i} \text{ (known and measured)} \tag{29a}$$

$$\Delta_3 = B_3 - \sum_{1} B_{3i} \text{ (known and measured)} \tag{29b}$$

in Tables 4 and 5. Remember, these compilations have many data sets in common, they are not statistically independent. Hayes (1992) has given an important discussion of the problems in compiling such tables.

Understanding the true errors in these average values is very difficult, as I remarked in the previous section. Are the systematic errors underestimated? Have the proper corrections been made for modes which have a K_L^0? In a particular decay mode, do almost all experiments have the same bias, a bias which is not corrected? Therefore, at this time it is probably best to take the errors in $\sum B_{1i}$ and $\sum B_{3i}$ to be of the order of 1%, and to recognize that at present we do not know if there are missing decay modes, modes which are unconventional and hence not detected and not measured.

It has long been recognized that these questions would be best answered by a single experiment in which every B_{1i} and B_{3i} has high statistics. We do not yet have such an experiment with sufficient statistics to reduce errors to a few tenths of a per cent, the size of errors we would like. The closest we come at present to such an experiment is that carried out by the ALEPH experimenters at LEP (Davier 1992). They find (Davier 1992) Δ_1 and Δ_3 to be zero within errors, and

$$\sum_u B_{1i} + \sum_i B_{3i} + B_5 = (99.9 + 1.3)\% \tag{30}$$

Table 6 (Snow 1992) shows a measurement set from the ALEPH experimenters.

Table 6. A complete set of branching fraction measurements from the ALEPH experimenters (SNOW 1992). The third error on $\sum B_i$ is the normalization uncertainty.

Decay Mode	B(%)
$e^- \bar{\nu}_e \nu_\tau$	$18.23 \pm 0.30 \pm 0.22$
$\mu^- \bar{\nu}_\mu \nu_\tau$	$17.70 \pm 0.29 \pm 0.21$
$h^- \nu_\tau$	$12.63 \pm 0.28 \pm 0.24$
$h^- \pi^0 \nu_\tau$	$26.04 \pm 0.57 \pm 0.63$
$h^- 2\pi^0 \nu_\tau$	$8.69 \pm 0.61 \pm 0.52$
$h^- \geq 3\pi^0 \nu_\tau$	$1.65 \pm 0.41 \pm 0.41$
$2h^- h^+ \nu_\tau$	$9.57 \pm 0.24 \pm 0.22$
$2h^- h^+ \geq 1\pi^0 \nu_\tau$	$5.42 \pm 0.26 \pm 0.34$
$\sum B_i$	$99.93 \pm 0.83 \pm 0.72 \pm 0.67$

Finally the speculations, and they are speculations. One of the persistent problems in dealing with these summation questions is that no reasonable model has appeared as to what unconventional decay could explain a nonzero Δ_1 or Δ_3 in Eq. 29. We have only speculations.

As a first example, suppose there is some unknown spin 1/2 charge particle, $c^{\pm}$, which can be produced via

$$\tau^- \to c^- + \gamma \tag{31}$$

If the c mass were different from the e or μ mass, it would not have been found in the searches for $\tau^- \to e^- + \gamma$ and $\tau^- \to \mu^- + \gamma$, Table 2. Could such a decay mode have a branching fraction of several per cent? The mode would be counted in B_1. It would not be counted in any conventional B_{1i} but might slip into

$$\tau^- \to \nu_\tau + \rho^- \to \nu_\tau + \pi^- + \pi^0 \tag{32}$$

if both γ's from the π^0 overlapped in the electromagnetic shower detector and were counted as one γ. But the great objection to this speculation is why would not $c^{\pm}$ have been seen in many other experiments, in

$$e^+ + e^- \to c^+ + c^- \tag{33}$$

for example.

I sometimes speculate that in some τ decays a new particle may be produced, a new particle which in turn decays to several photons and other particles. The general form of the decay would be

$$\tau^- \to \text{normal decay products} + \text{extra } \gamma\text{'s} \tag{34}$$

Such a decay would be counted in measuring B_1 and B_3 but the extra photons, since they do not come from π^0's, might prevent these decays from being counted in any conventional τ decay mode. Or, if the decay in Eq. 34 were counted, it would appear incorrectly in the set of modes.

$$\tau^- \to \nu_\tau + h^- + n\pi^0 \quad , \; n \geq 2 \tag{35a}$$
$$\tau^- \to \nu_\tau + h^- + h^+ + h^- + n\pi^0 \quad , \; n \geq 2 \tag{35b}$$

Figure 5 shows two forms of this speculation. In Fig. 5a the new particle N is produced at the $\tau - W$ vertex, and N subsequently decays to ν_τ and several photons. In Fig. 5b an unknown particle couples to the $\tau - \nu_\tau$ vertex and subsequently decays to several photons and leptons or quarks.

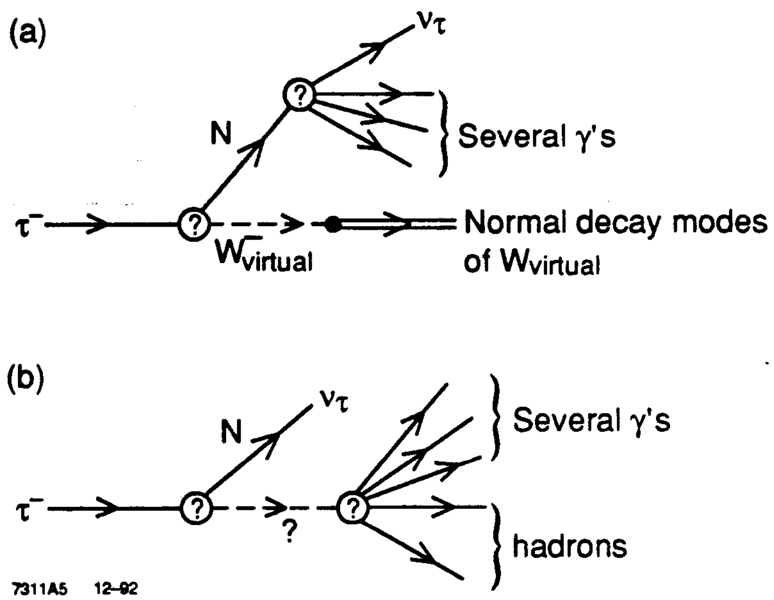

Figure 5.

There are certainly problems with this speculation. Can there be a new particle as required in Fig. 5a or 5b which would not have been found anywhere else in particle physics? And there is an experimental limitation, the ALEPH experimenters (Davier 1992) have placed an upper limit of 2.4% on the branching fraction of modes with photons not coming from π^0's.

It seems to me that at present it is impossible to know whether $\Delta_1 + \Delta_3$ in Eqs. 29 is consistent with zero, or whether there are unknown τ decay modes which are making $\Delta_1 + \Delta_3$ nonzero. Perhaps it is best to adopt the conservative attitude that there is no definite experimental evidence for a nonzero $\Delta_1 + \Delta_3$. Or perhaps it is best to be hopeful to continue to examine these summation issues.

In the end we need much more precise experiments with errors at the 0.1% level rather than the present 1 or 2% level. The tau-charm factory is the ideal machine for such experiments.

C. Searches in Charm Physics

There are six powerful advantages in studying the physics of the charm mesons at the tau-charm factory at the Ψ'' and at the D_s threshold energies:

- The ability to produce very large data sets over short collection times.

- The ability to cleanly select D and D_s by single-tagging of the events. That is, only one D or D_s decay is identified in order to select the pair in an event.
- The availability of kinematic constraints using the beam energy for the rejection of backgrounds.
- The production of the D meson pair in an initial state that is also a coherent quantum mechanical state, allowing further background control and also allowing certain unique physics studies to be performed.
- The absence of backgrounds from heavier meson decays, since production is at threshold.
- The ability to *directly* measure, as necessary, backgrounds from non-charm events by moving below the Ψ'' resonance or below the D_S threshold.

C.1 Unconventional D Decays to Known Particles

A D decay which violates lepton number conservation could be evidence for the existence of a new particle. Examples with present 90% CL upper limits on the branching fraction are:

$$\begin{array}{ll}
\text{Mode} & B \\
D^0 \rightarrow e^{\pm} + \mu^{\mp} & < 1.0 \times 10^{-4} \\
D^+ \rightarrow \pi^+ + e^{\pm} + \mu^{\mp} & < 3.3 \times 10^{-3} \\
D^+ \rightarrow K^+ + e^{\pm} + \mu^{\mp} & < 3.4 \times 10^{-3} \\
D^+ \rightarrow \pi^- + e^+ + e^+ & < 4.8 \times 10^{-3} \\
D^+ \rightarrow \pi^- + e^+ + \mu^+ & < 3.7 \times 10^{-3}
\end{array} \tag{36}$$

At a tau-charm factory the search for such decays can be carried down to branching fractions of 10^{-7} to 10^{-8}. Stockdale (1989) and Willy (1989) have discussed such searches.

C.2 D Decays Through a Flavor-Changing Neutral Weak Current

In the standard model, decays through a flavor-changing neutral weak current will not occur in lowest order. The general form of such decays is

$$D = \ell^+ + \ell^- + h \tag{37}$$

where

$$\begin{aligned}
&D = D^0 \text{ or } D^{\pm} \\
&\ell^+\ell^- = e^+e^- \text{ or } \mu^+\mu^- \\
&h = \pi \text{ or } K \text{or } \rho
\end{aligned}$$

But as shown in Fig. 6, these decays can occur in the standard model in higher order, and branching fractions of the order of

$$B \sim 10^{-7} \tag{38}$$

can be expected (Wiley 1989).

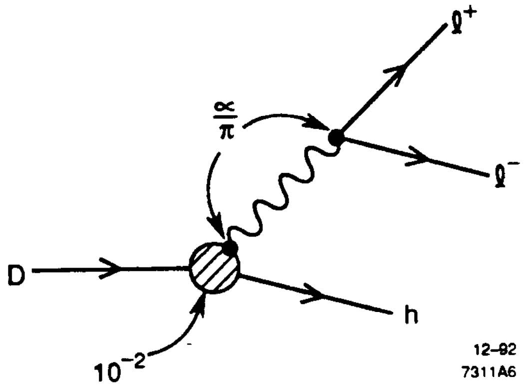

Figure 6.

However, if a D decay of the type in Eq. 37 occurs with a larger branching fraction, it could show the existence of a new particle intermediate in the decay process. Therefore, it is important to search for such decays down to branching fractions of 10^{-8}. This can be done with a tau-charm factory (Stockdale 1989).

It is interesting to look at some present 90% CL upper limits.

$$\begin{array}{cl} \mathit{Mode} & \quad B \\ D^0 \to e^+ + e^- & < 1.3 \times 10^{-4} \\ D^+ \to \mu^+ + \mu^- & < 1.1 \times 10^{-5} \\ D^+ \to \rho^0 + e^+ + e^- & < 4.5 \times 10^{-4} \\ D^+ \to \pi^+ + e^+ + e^- & < 2.5 \times 10^{-3} \\ D^+ \to \pi^+ + \mu^+ + \mu^- & < 2.9 \times 10^{-3} \end{array} \tag{39}$$

Finally a very interesting set of decays involves neutrinos:

$$\begin{gathered} D^0 \to \nu + \bar{\nu} \\ D^+ \to h^+ + \nu + \bar{\nu} \end{gathered} \tag{40}$$

C.3 Charmonium Decays

At a tau-charm factory experimenters can produce $10^9 J/\psi$'s per month and $0.5\times 10^9 \psi'$'s per month, thus an enormous number of J/ψ and ψ' decays can be acquired. As discussed by Toki (1989) and Burnett (1989), this allows powerful searches for rare and unconventional decays, decays which could lead to the discovery of new particles. I list some of these decays.

There are the weak decay

$$J/\psi \rightarrow D_s + \text{ hadrons} \tag{41a}$$
$$J/\psi \rightarrow D_s + \ell + \nu_\ell \tag{41b}$$

Note that the weak decay of a vector meson has never been seen.

A decay through an unknown neutral particle, x^0, might occur.

$$J/\psi \rightarrow \gamma + x^0 \ , \ x^0 \rightarrow \mu^+ + \mu^- \tag{42}$$

The x^0 might be a Higgs particle.

Once again there are the weak neutral current decays.

$$J/\psi \rightarrow \nu + \bar{\nu}$$

which could be detected through the sequence

$$\psi' \rightarrow \gamma + J/\psi \ , \ J/\psi \rightarrow \nu + \bar{\nu} \tag{43}$$

And finally, the enormous number of J/ψ's allows the search for all sorts of axion-like particles

$$J/\psi \rightarrow \gamma + a \tag{44}$$

I conclude this section and the paper with the basic motto of all new particle searches, a motto slightly modified from a fortune cookie:

She that seeks will find.

He that seeks will find.

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