A Study of Decays of the Tau Lepton with Charged Kaons

by

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Abstract

Precise studies of the decays of the tau (τ^-) lepton have been made possible by the availability of large, low-background tau samples, such as those produced in e^+e^- collisions at the Z^0 resonance at LEP. This thesis describes a study of tau decay modes containing charged kaons, using data collected by the OPAL experiment at LEP. A charged kaon (K^-) is a meson composed of a bound state of a strange quark and an up anti-quark, and has a mass of 0.492 GeV/c^2. Another example of a meson is the charged pion (π^-) , which is composed of a down quark and an up anti-quark, and has a mass of 0.139 GeV/c^2. Charged pions are often produced in tau decays, but decays including charged kaons only occur approximately 5% of the time. One way to experimentally distinguish between the predominant charged pions and the kaons in tau decays is to determine the energy lost by the particle as it traverses a gas and ionises molecules in that gas; the energy lost in this process is a function of the particle mass.

The OPAL detector provides precise measurements of the ionisation energy loss of charged particles, and it is primarily this capability that is exploited in this work to study these tau final states and obtain precise measurements of their branching ratios.

Appendix A

Phenomenological Parameterisation of Resonant Amplitudes

The amplitude for the production of a resonant state of mass M_0 and width Γ_0 in a multi-particle decay is usually parameterised as a function of the energy $\mathcal{Q}$ using the Breit-Wigner form such as [68]:

$$\mathcal{A}(\mathcal{Q}) = \frac{M_0^2}{(\mathcal{Q}^2 - M_0^2 + iM_0\Gamma_0)}. \tag{A.1}$$

In the neighbourhood of the pole of a very narrow resonance, equation A.1 yields a good approximation to the experimentally observed $|\mathcal{A}|^2$. However, the correct threshold behaviour of $|\mathcal{A}|^2$ for wide resonances can only be achieved if the width of the resonance in Equation A.1 is a function of $\mathcal{Q}$ [68]:

$$\mathcal{A}(\mathcal{Q}) = \frac{M_0^2}{(\mathcal{Q}^2 - M_0^2 + iM_0\gamma_0(\mathcal{Q}))}. \tag{A.2}$$

The following is a discussion of the parameterisation of γ_0 for the decay of a resonance to two stable particles, and for the quasi-two-body decay of a resonance to a final state which consists of a stable particle and a second resonance [56].

A.1 Decay of a Resonance to Two Stable Particles

For the decay of a resonance of mass M_0, width Γ_0, and orbital angular momentum l, to a final state which consists of two stable particles of masses m_1 and m_2, we have that the energy dependent width is:

$$\gamma_0(\mathcal{Q}, m_1, m_2) = \Gamma_0 \frac{\rho(\mathcal{Q}, m_1, m_2)}{\rho(M_0, m_1, m_2)}, \tag{A.3}$$

where

$$\rho(\mathcal{Q}, m_1, m_2) = \Big[a(\mathcal{Q}, m_1, m_2)\Big]^{(2l+1)/2},$$

and where

$$a(\mathcal{Q}, m_1, m_2) = \frac{[\mathcal{Q}^2 - (m_1 + m_2)^2][\mathcal{Q}^2 - (m_1 - m_2)^2]}{4\mathcal{Q}^2}. \tag{A.4}$$

The function $a(\mathcal{Q})$ is taken to be zero if $\mathcal{Q} < (m_1 + m_2)$.

A.2 Decay of a Resonance to a Stable Particle and a Secondary Resonance

Now consider the quasi-two-body decay of a primary resonance of mass M and width Γ to a final state which consists of a stable particle of mass m_3 and a second resonance of mass M_0 and width Γ_0, which in turn decays to two stable particles of masses m_1 and m_2. The orbital angular momentum of the primary resonance is

L, and its energy dependent width is given by:

$$\gamma(\mathcal{Q}, m_1, m_2, m_3) = \Gamma \frac{\rho(\mathcal{Q}, m_1, m_2, m_3)}{\rho(M, m_1, m_2, m_3)},$$

where

$$\rho(\mathcal{Q}, m_1, m_2, m_3) = \int_{m_1+m_2}^{\mathcal{Q}-m_3} \sigma(\mathcal{M}, M_0, m_1, m_2) \Big[a(\mathcal{Q}, m_3, \mathcal{M}) \Big]^{(2L+1)/2} d\mathcal{M},$$

and where the function $a(\mathcal{Q}, m_3, \mathcal{M})$ is the same as in Equation A.4. The distribution function $\sigma(\mathcal{M}, M_0, m_1, m_2)$ is

$$\sigma(\mathcal{M}, M_0, m_1, m_2) = \frac{\gamma_0(\mathcal{M}, m_1, m_2)/2\pi}{(\mathcal{M} - M_0)^2 + (\gamma_0(\mathcal{M}, m_1, m_2)/2)^2},$$

where the function $\gamma_0(\mathcal{M}, m_1, m_2)$ is the same as in Equation A.3.

Note that $\gamma(\mathcal{Q}, m_1, m_2, m_3)$ is, in general, non-zero if the mass of the secondary resonance exceeds that of the primary resonance. However, $\gamma(\mathcal{Q}, m_1, m_2, m_3)$ will be zero if $\mathcal{Q} < (m_1 + m_2 + m_3)$.

Also note that in the limit $\Gamma_0 \to 0$ we have that $\sigma(\mathcal{M}, M_0, m_1, m_2) \to \delta(\mathcal{M} - M_0)$, and ρ becomes a function of only $\mathcal{Q}$, M_0, and m_3 (ie; the quasi-two-body decay can now be treated as a two-body decay).