Measurement of the presence of $a_1(1420)$ and $\omega(782)$ in $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ at Belle

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Abstract

We present preliminary results of a partial-wave analysis of $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ using data from the Belle experiment at the KEKB e^+e^- collider. We validate our model with a model-independent analysis. We see the $a_1(1420)$ and a G-parity-violating $1^-[\omega(782)\,\pi]_P$ wave in tauon decays. Our results will improve models used in simulation studies necessary for measuring the electric and magnetic dipole moments and Michel parameters of the τ.

1 Introduction

Many studies of spin correlation in $e^+e^- \to \tau^+\tau^-$, such as measuring the electric and magnetic dipole moments of the τ, analyze tauon decay to $\pi^-\pi^+\pi^-\nu_\tau$ [1].[1] However, lack of knowledge about $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$, which has never been analyzed for intermediate resonances, limits the precision of such measurements.

This decay proceeds predominantly through $a_1(1260)$, a broad unflavored ground-state axial-vector meson [2], whose resonance shape is poorly known [3–5]. What other resonances are present and in what amounts are also poorly known. The COMPASS and VES experiments observed the $a_1(1420)$, potentially a narrow unflavored axial-vector meson, in pion-proton scattering [6, 7]. Seeing it in $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ and measuring how present it is in the decay will clarify whether it is a particle or an artifact of K^*K scattering [8].

To study such matters, we perform a partial-wave analysis (PWA) of $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ using 980 fb^{-1} of data collected by the Belle experiment [9] at the asymmetric e^+e^- collider KEKB [10]. Consult [9] for details of the Belle detector.

2 Event selection

Using simulated data, we optimized our event selection to maximize the statistical precision of our results without introducing significantly uneven detection efficiency across the decay's phase space. Each event has two hemispheres defined by the thrust axis calculated using all detected charged particles and photons. We require there be three charged particles in one, the signal hemisphere, and one in the other, the tag hemisphere.

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[1] Inclusion of charge-conjugated decays is assumed throughout.

We use a boosted decision tree (BDT), implemented with ROOT's TMVA software [11], to remove events not coming from $e^+e^- \to \tau^+\tau^-$. It is trained on simulated data and bases its decision on the sum of the momenta of charged particles and photons, the sum of energies of charged particles, the missing mass, the cosine of the polar angle of the missing momentum, the energy detected in the electromagnetic calorimeter, and the event thrust; the last is the most discriminating. All frame-dependent variables are calculated in the e^+e^- center-of-momentum frame.

We veto the presence of charged kaons in the signal hemisphere by requiring the two particles with like charges be consistent with being pions. We veto the presence of neutral kaons by requiring the mass of each pair of oppositely charged pions in the signal hemisphere be more than 12 MeV from the known K^0 mass [5]. And we reduce the presence of neutral pions by requiring the sum of photon energies in the signal hemisphere be below 480 MeV, summing over photons with at least 40 MeV.

We find 55×10^6 events, with 82% purity and 32% efficiency to find signal—the largest sample of $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ yet analyzed. Background events come mostly from $e^+e^- \to q\bar{q}$, with $q = u, d, s, c$, and from $e^+e^- \to \tau^+\tau^-$ with the τ in the signal hemisphere decaying to $\pi^-\pi^+\pi^-\pi^0$. We use a neural network to model the background in our partial-wave analysis; see [12, 13] for more details.

3 Partial-wave analysis

The phase space of $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ has seven dimensions. We parameterize our model intensity in the helicity angle of the ν_τ, the Euler angles of the three pions in the τ rest frame, the $\pi^+\pi^-$ squared masses, s_1 and s_2, and the mass of the three pions, $m_{3\pi}$ [14]. We average the intensity over the Euler angle that is unmeasurable because the ν_τ cannot be detected [13].

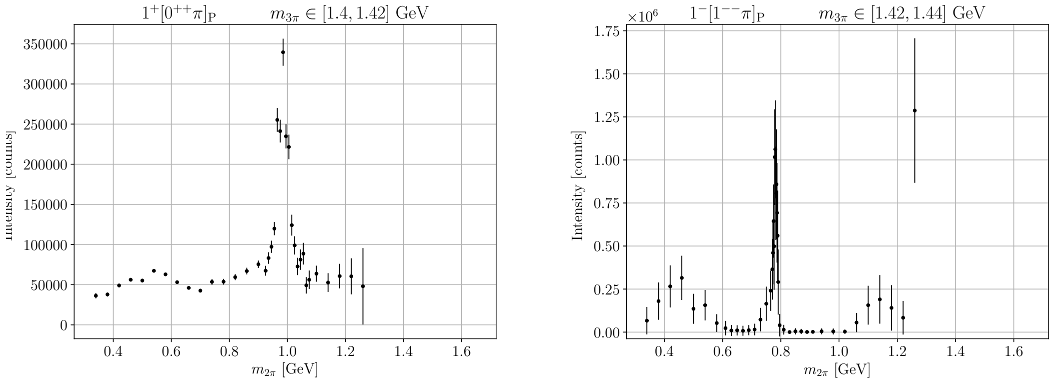
We fit to the data independently in disjoint contiguous bins of $m_{3\pi}$ to decompose it into partial waves using an isobar model and the tensor formalism of [15]. We assume that the decay proceeds through a resonance X^- that decays to three charged pions via a sequence of two-body decays, $X^- \to \xi^0\pi^-$ and $\xi^0 \to \pi^-\pi^+$, where ξ^0 is an isobar. The only requirement on X^- in the partial-wave decomposition is that its spin and parity, J^P, be 0^-, 1^+, or 1^-; the presence of the last would violate G parity.

We allow ξ^0 to be $\rho(770)$, $\rho(1450)$, $f_0(500)$, $f_0(980)$, $f_0(1500)$, $f_2(1270)$, or $\omega(782)$. We model them all with the relativistic Breit-Wigner function with masses and widths the same as in the COMPASS PWA [3], except for the $f_0(500)$, which we model with the broad $(\pi\pi)_S$ component described in [16]. Angular momentum up to 3 is allowed between ξ^0 and the remaining pion. We denote a partial wave by $J^P[\xi^0\pi]_L$ for specific isobar resonances ξ^0 and $J^P[(\pi\pi)_j\pi]_L$ for generic isobars with spin j, with L the total angular momentum.

The preliminary results of the PWA were presented in [17]. Here we present an update that includes systematic uncertainties. We observe that the most intense partial wave is the $1^+[\rho(770)\pi]_S$ wave, with a fit fraction of $(76.42 \pm 0.05 \pm 3.29)\%$, where the first uncertainty is statistical, and the second uncertainty is systematic. The next most intense is the $1^+[\sigma\pi]_P$ wave with a fit fraction of $(8.40 \pm 0.02 \pm 1.16)\%$. The fit fraction of a partial wave is the integral over $m_{3\pi}$ of the intensity of that wave alone divided by the same integral of the intensity of the full PWA model. These fractions agree with those measured by CLEO II in $\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$ [4].

We use quasi-model-independent PWA (QMIPWA) [18] to verify our model. We replace the $(\pi\pi)_S$ and $1^+[\rho(770)\pi]_S$ models with complex step functions, letting the fit optimize their values [17]. We observe the narrow peak of the $f_0(980)$ in the $(\pi\pi)_S$ wave, as shown in Fig. 1a.

In [19], Mirkes and Urech stated that 1^- intensity in $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ comes from the



a) $1^+[(\pi\pi)_S\,\pi]_P$ wave.

b) $1^-[(\pi\pi)_P\,\pi]_P$ wave.

Figure 1: QMIPWA intensities as functions of $m_{2\pi}$ with statistical uncertainties.

G-violating decay of $\omega(782) \to \pi^+\pi^-$, where $\omega(782)$ is produced by decay of a $\rho(770)$, $\rho(1450)$, or $\rho(1700)$. We free the $1^-[(\pi\pi)_P\,\pi]_P$ wave in our QMIPWA and observe a narrow peak at 782 MeV, as shown in Fig. 1b. We include the $1^-[\omega(782)\,\pi]_P$ wave in the conventional PWA and measure a fit fraction of $(2.95\pm0.04)\times10^{-3}$, consistent with the prediction of 4×10^{-3} in [19].

4 Conclusion

We will soon provide an updated model for $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ with about 15 partial waves and statistical and systematic uncertainties. It will be useful for simulating $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$, necessary for measurement of the electric and magnetic dipole moments of the τ. We see the $a_1(1420)$ and $1^-[\omega(782)\,\pi]_P$ wave in tauon decays in both conventional PWA and QMIPWA. This is their first sighting in tauon decay.

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