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A Search for the lepton-flavour violating Decays $\tau \rightarrow e\alpha$, $\tau \rightarrow \mu\alpha$

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Abstract

Lepton spectra in τ decays have been studied with the ARGUS detector at the e^+e^- storage ring DORIS II at DESY using the "pseudo-rest-frame" technique. We have improved upper limits for two-body τ -decays into a lepton and an unobservable particle.

The problem of fermion families remains one of the central problems in particle physics. The standard $SU(3) \times SU(2) \times U(1)$ model, as well as its possible "vertical" extensions in the one family framework like SU(5), SU(10) etc., cannot explain the fermion mass hierarchy and weak mixing pattern due to the arbitrariness of the Yukawa couplings. In one attempt to solve this problem a Goldstone boson α is introduced which is simultaneously axion (or arion), singlet Majoron and familion [1-2]. Flavour nondiagonal transitions with α emission induce the decays $\tau \to e\alpha$ and $\tau \to \mu\alpha$.

In this paper we report on a search for two-body decays of τ into a light lepton (electron or muon) and an unobservable particle α using the ARGUS detector at the e^+e^- storage ring DORIS II.

Previously, upper limits for $\tau \to e\alpha$ ($\tau \to \mu\alpha$) decays have been presented by the Mark III [3] and ARGUS [4] collaborations (see Table 1). The upper limits for α masses below

Table 1: Measured branching ratios of 2–body τ decays into a lepton and an unobservable particle α.

Experiment	$B(\tau \to e\alpha)/B(\tau \to e\nu\overline{\nu})$	$B(\tau \to \mu\alpha)/B(\tau \to \mu\nu\overline{\nu})$
for α with mass less than 100 MeV/c^2		
Mark III	$< 4.0\%$	$< 12.5\%$
ARGUS 90	$< 1.8\%$	$< 3.3\%$
for α with mass equal 500 MeV/c^2		
ARGUS 90	$< 5.0\%$	$< 7.1\%$

0.5 GeV/c^2 were obtained from a fit of the lepton spectra in the laboratory frame in the high momentum region. The expected momentum spectra of leptons resulting from $\tau \to \ell\nu\overline{\nu}$ and $\tau \to \ell\alpha$ are shown in Fig. 1.

It is best to search for $\tau \to \ell\alpha$ decays in the τ rest frame. Here the lepton momentum distribution is shaped as a peak with a position depending on the α mass. To perform the Lorentz boost to this frame one needs to know the τ flight direction. This is not directly measured at ARGUS. However, for events where the second τ lepton decays into $(3h)^{\pm}\nu_\tau$ or $(3h)^{\pm}\pi^0\nu_\tau$, this direction can be well approximated by the momentum vector of the heavy

3-prong system [5]. Using in addition the fact that the τ energy coincides with the beam energy up to initial state radiative corrections, the momentum vector of the τ lepton can be approximated, and hence a transformation to the τ pseudo rest frame becomes possible. Therefore, we select $\tau^+\tau^-$ pairs with one τ decaying into a lepton and two neutrinos (or into a lepton and α) and the other τ decaying into $(3h)^{\pm}\nu_\tau$ or $(3h)^{\pm}\pi^0\nu_\tau$. The difference between the spectra of 2–body ($\tau \to \ell\alpha$) and 3–body ($\tau \to \ell\nu\overline{\nu}$) τ decays is illustrated in fig.1, where we present the lepton momentum spectra in the laboratory and τ pseudo rest frames. As estimated with Monte Carlo the maximum sensitivity in the laboratory frame is achieved for zero α mass, degrading with increasing mass. In contrast, the τ pseudo rest frame sensitivity for α is more or less constant with respect to the α mass.

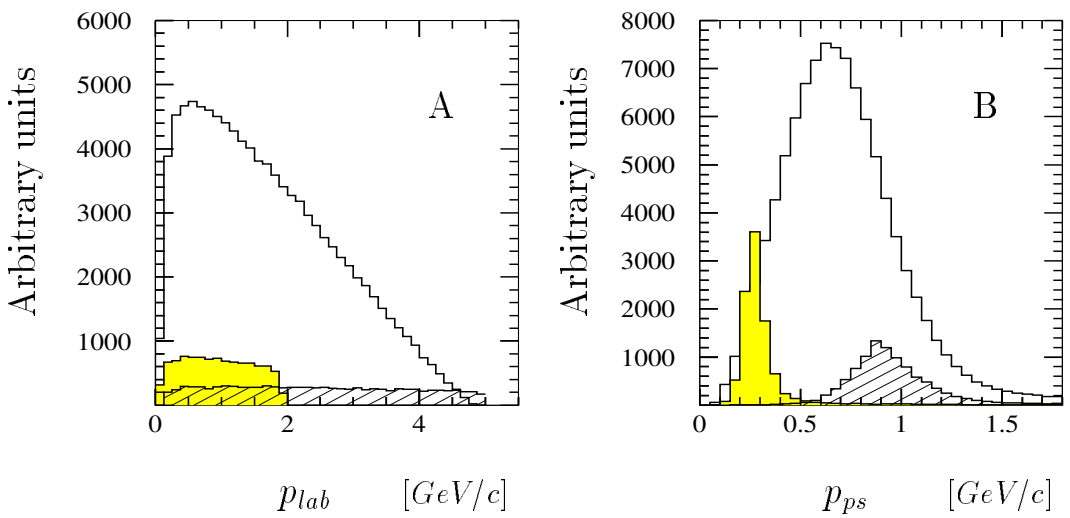

Figure 1: Monte Carlo prediction for momentum spectra of leptons from the decays $\tau \to \ell\nu\overline{\nu}$ (histogram), $\tau \to \ell\alpha$ with $m_\alpha = 0$ (hatched histogram), and $\tau \to \ell\alpha$ with $m_\alpha = 1.4$ GeV/c^2 (shadowed histogram). Spectra are shown in the laboratory frame (fig.1a) and in the τ pseudo rest frame (fig.1b). For display purposes the ratio of branching fractions $B(\tau \to \ell\alpha)/B(\tau \to \ell\nu\overline{\nu})$ was set to 10%.

The data sample for this analysis was collected at center-of-mass energies between 9.4 and 10.6 GeV, corresponding to an integrated luminosity of 472 pb^{-1}. The description of the ARGUS detector,trigger conditions and particle identification may be found in detail elsewhere [6]. For electron identification, information from all detector components was used coherently by combining the measurements into an overall likelihood ratio. The available information consisted of dE/dx and time-of-flight measurements, and the magnitude and

topology of energy deposition in the shower counters. The corresponding electron likelihood was required to be greater than 80%. Muons were defined as charged tracks having at least one hit in the outer layers of muon chambers and energy deposition in the calorimeter less than 0.5 GeV. Particles with a pion likelihood ratio larger than 1% were accepted as pions. Photons were identified as energy deposits in the shower counters not associated with a charged track. Their energy had to exceed 0.08 GeV.

The experimental electron and muon momentum spectra were obtained from the sample of tau pair events in a 1-versus-3 topology with the one prong particle being a lepton. Our selection criteria were essentially the same as those applied in previous studies of τ decays [4,5,7-9]. We required exactly four charged tracks originating from the interaction vertex with a zero net charge. Since τ leptons are produced back-to-back with large momenta their decay products point into opposite hemispheres. So we applied the following criteria:

- $\cos(\vec{p}_1, \vec{p}_i) < 0 \quad (i = 2,3,4)$
- $\cos(\vec{p}_i, \vec{p}_j) > 0 \quad (i,j = 2,3,4)$
- $\cos(\vec{p}_1, \sum_{i=2}^{4} \vec{p}_i) < -0.5$

where $\vec{p}_1$ denotes the momentum of the charged particle on the one-prong side and $\vec{p}_i \quad (i = 2,3,4)$ are the particle momenta on the three-prong side. The single-prong track had to point into the barrel region of the detector $|\cos(\theta)| \leq 0.75$, in order to ensure good momentum resolution and trigger conditions.

The following restrictions were made to reduce the two photon and QED backgrounds to a negligible level. We applied a cut on a relation between the transverse momentum balance and the total visible momentum of the charged particles [8]

$$|\sum_{i=1}^{4} \vec{p}_{T_i}| > (4.5 \cdot (\sum_{i=1}^{4} \frac{p_i \cdot c}{E_{cms}} - 0.55)^2 + 0.1) \text{ GeV/c}$$

where $\vec{p}_{T_i}$ is the transverse momentum of the i-th particle. The shower energy of all charged particles on the three-prong side released in the calorimeter was limited to 3.5 GeV. On the three-prong side the cosine of the angle between oppositely charged particles was required to be less than 0.992. To decrease the $q\bar{q}$ contamination we allowed no more than two photons on the 3-prong side.

In a second selection stage we applied cuts specific to the decay channels $\tau \to e\nu\overline{\nu}$ and $\tau \to \mu\nu\overline{\nu}$ correspondingly.

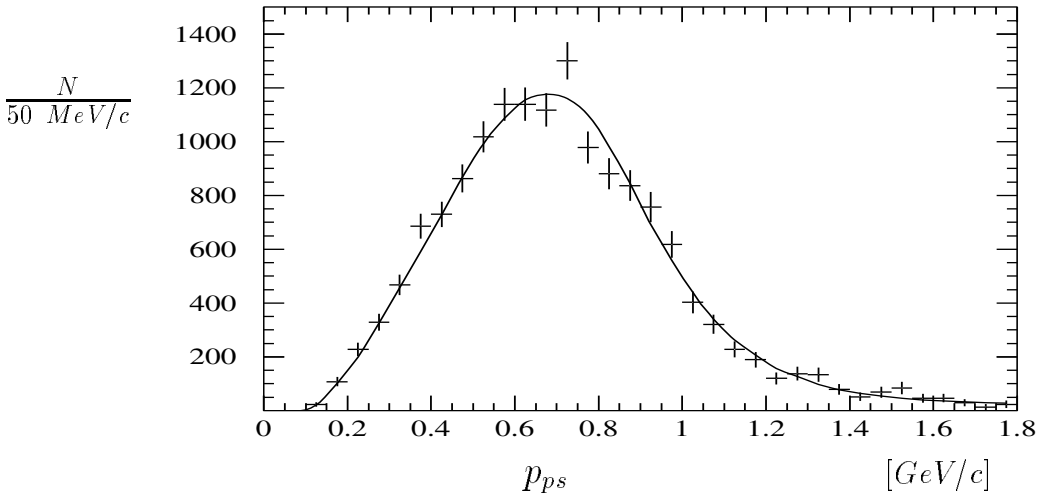

Figure 2: Efficiency corrected electron momentum spectrum in the τ pseudo rest frame (points with error bars). The solid line represents a fit to the data assuming no contribution from the decay $\tau \to e\alpha$.

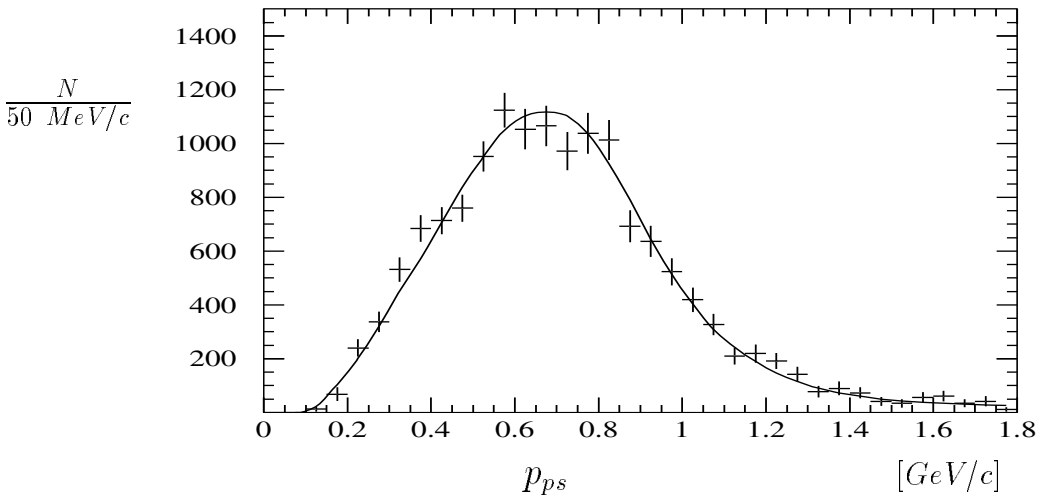

Figure 3: Efficiency corrected muon momentum spectrum in the τ pseudo rest frame (points with error bars). The solid line represents a fit to the data assuming no contribution from the decay $\tau \to \mu\alpha$.

Electrons were required to have momenta greater than 400 MeV/c. In this region the detection efficiency is about 90% and the pion fake rate is 0.5% [4]. The polar angle θ_{mis} of the missing momentum was restricted by the requirement $q_e \cdot \cos(\theta_{mis}) \geq -0.9$, where q_e is the charge of the detected electron (positron). We have allowed no more than one photon on the one prong side. The photon energy was limited to 300 MeV. The electron sample consisted of 5055 events with 25 and 17 events resulting from $q\bar{q}$ contamination and pion misidentification, respectively.

For the muon sample the selection procedure depended on the lepton momentum. Muon candidates with laboratory momentum $p_{lab} > 1.5$ GeV/c were required to have hit at least one chamber of the outer layer. In this case the detection efficiency is about 85% and pion fake rate is 2.5%. To suppress the $\tau \to e\nu\overline{\nu}$ decay contribution the electron likelihood ratio of the charged track was required to be less than 0.5. In order to suppress background from $\tau \to \rho\nu_\tau$ we required that no photons be present on the one–prong side and that the shower energy associated with the charged track be less than 0.5 GeV. The use of the τ pseudo rest frame method enables the separation of muons from the background at laboratory momenta p_{lab} below 1.5 GeV/c, where identification strategies based on muon penetration through absorber do not work. The backgrounds in this momentum range are mainly due to one-prong τ decays into hadrons. A major fraction of two–body hadronic τ decays peaks in the high momentum region in the τ pseudo rest frame. This component was rejected by requiring $p_{ps} < 0.6$ GeV/c. The number of events for each part of the muon spectrum is presented in Table 2. The efficiency corrected and background subtracted spectra of electrons and muons in the τ pseudo rest frame are shown in fig.2 and 3.

The background contributions from the τ decays and the acceptance for the investigated τ decays were estimated from Monte Carlo using the KORALB/TAUOLA generator, the ARGUS detector simulation and subsequent event reconstruction [10-13]. The τ decays into a lepton and an unobservable particle α were generated according to the available phase space.

The efficiency corrected experimental spectra were fit to a sum of the theoretical expectations for 3– and 2–body τ decays for different masses of α. We have found no excess expected for the $\tau \to \ell\alpha$ decays in the whole kinematically allowed region of α mass. The upper limits on the ratio of the branching fraction of the decay $\tau \to \ell\alpha$ to decay $\tau \to \ell\nu\overline{\nu}$ were obtained by a least squares method as a function of α mass. In fig.4 the results are presented in terms of the ratio of the branching fraction of 2–body decay $\tau \to \ell\alpha$ to the branching fraction of 3–body decay $\tau \to \ell\nu\overline{\nu}$.

Table 2: Backgrounds and number of events for the soft and hard parts of the muon spectrum

Decay	**Number of events**	
	$p_{ps} < 0.6$ GeV/c	$p_{ps} > 0.6$ GeV/c (hit in the muon chambers is required)
$\tau \to \rho\nu_\tau$	123 ± 12	4 ± 2
$\tau \to \pi\nu_\tau$	65 ± 8	57 ± 11
$e^+e^- \to q\overline{q}$	45 ± 7	6 ± 3
$\tau \to K^\star\nu_\tau$	30 ± 10	negligible
$\tau \to K\nu_\tau$	16 ± 6	4 ± 2
$\tau \to e\nu\overline{\nu}$	10 ± 4	negligible
other τ decays	13 ± 7	negligible
$\tau \to \mu\nu\overline{\nu}$	1914 ± 52	1915 ± 44

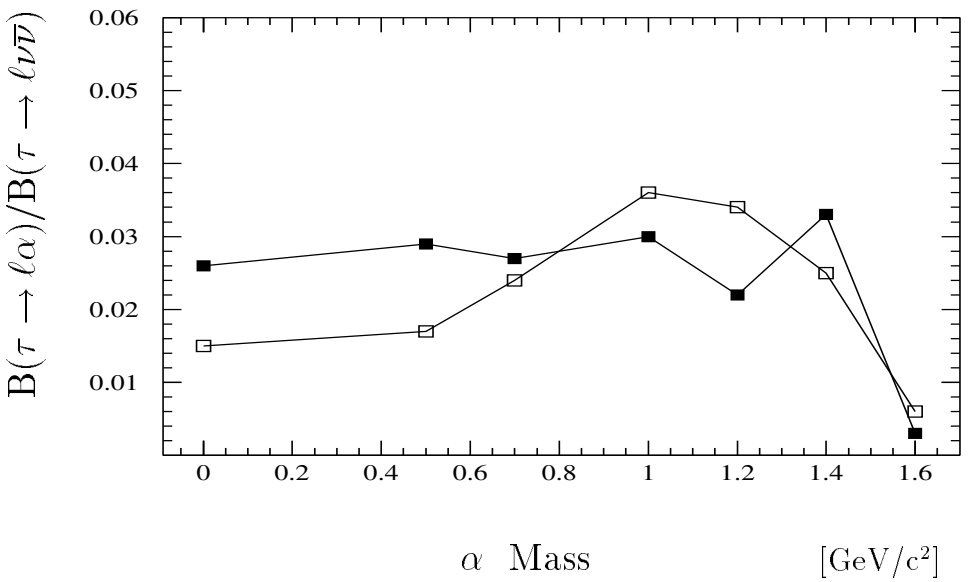

Figure 4: The upper limits at 95% confidence level on the ratio $\mathrm{B}(\tau \to \ell\alpha)/\mathrm{B}(\tau \to \ell\nu\overline{\nu})$ for electrons (open squares) and muons (full squares)

In summary, a detailed study of the lepton momentum spectra for τ decays into a lepton and an unobservable particle has been performed using the "τ pseudo rest frame" technique. This method yields an improved upper limit on the ratio $B(\tau \to \ell\alpha)/B(\tau \to \ell\nu\overline{\nu})$. No evidence was found for 2–body τ decays into a lepton and an unobservable particle α for α masses up to 1.6 GeV/c^2. For a massless α we set the following upper limits at 95% confidence level: $B(\tau \to e\alpha)/B(\tau \to e\nu\overline{\nu}) < 1.5\%$ and $B(\tau \to \mu\alpha)/B(\tau \to \mu\nu\overline{\nu}) < 2.6\%$.

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References

[1] B.Grinstein, J.Preskill and M.B.Wise, Phys.Lett. **159B** (1985) 57.

[2] Z.G.Berezhiani, M.Yu.Khlopov, Z.Phys. **C49** (1991) 73.

[3] MARK III Collab., R.M.Baltrusaitis *et al.*, Phys.Rev.Lett. **55** (1985) 1842.

[4] ARGUS Collab., H.Albrecht *et al.*, Phys.Lett. **B246** (1990) 278.

[5] ARGUS Collab., H.Albrecht *et al.*, Phys.Lett. **B341** (1995) 441

[6] ARGUS Collab., H.Albrecht *et al.*, Nucl. Instr. Meth. **A275** (1989) 1

[7] ARGUS Collab., H.Albrecht *et al.*, Phys. Lett. **B250** (1990) 164

[8] ARGUS Collab., H.Albrecht *et al.*, Z. Phys. **C58** (1993) 61

[9] ARGUS Collab., H.Albrecht *et al.*, Phys. Lett. **B292** (1992) 221

[10] H.Gennow, "Simarg: A Program to simulate the ARGUS detector", DESY internal note, DESY **F15-85-02** (1985)

[11] S.Jadach and Z.Was, Comp. Phys. Comm. **66** (1991) 267

[12] S.Jadach, J.H.Kuhn, and Z.Was, Comp. Phys. Comm. **66** (1991) 275

[13] E.Barberio, B. van Ejik, and Z.Was, Comp. Phys. Comm. **66** (1991) 115