SLAC-PUB-2058
December 1977
(T)

COMMENT ON THE ABSENCE OF THE PIONIC MODE IN τ DECAY†

Yongzik Ahn*
Department of Physics, Seoul National University
Seoul 151, Korea

and

Jewan Kim**
Department of Physics, The Johns Hopkins University
Baltimore, Md. 21218 U.S.A.

and

H. S. Song**
Stanford Linear Accelerator Center
Stanford University, Stanford, Ca. 94305 U.S.A.

ABSTRACT

A possible suppression of the pionic mode in the τ decay is discussed under the assumption of τ being a spin 3/2 object. The computed branching ratios are compared with existing data.

(Submitted to Phys. Letters)

†Work supported in part by Euisok Foundation, Seoul, Korea , the National Science Foundation, and the Department of Energy.

*Present address: Naval Academy, Ginhae, Korea.

**On leave of absence from Seoul National University under the S.N.U.- AID program of Basic Sciences.

The anomalous $e\mu$ events observed by M. Perl et al.[1] and confirmed by others[2] are now being interpreted as being due to the decay production of a pair of spin 1/2 heavy leptons. The experimental cross section $\sigma_{e\mu}$ is fitted by the formula

$$\sigma_{e\mu}(s) = 2A_{e\mu}(s)B_e B_\mu \sigma^{\frac{1}{2}}_{\tau\tau}(s)$$

where

$$\sigma^{\frac{1}{2}}_{\tau\tau}(s) = \frac{2\pi\alpha^2\beta(3-\beta^2)}{3s}$$

is the calculated cross section of $e^+e^- \to \tau^+\tau^-$ assuming that the τ lepton is a spin 1/2 point particle. B_e and B_μ are the leptonic branching ratios of $\tau \to \nu_\tau e \bar{\nu}_e$ and $\tau \to \nu_\tau \mu \bar{\nu}_\mu$, respectively. $A_{e\mu}$ is a calculated acceptance in the experiments and βc is the velocity of τ. The reported values of B_e and B_μ are around 0.18[3], consistent with the spin 1/2 lepton assignment of τ. The observed momentum distribution in terms of $r = \frac{P - 0.65}{P_{max} - 0.65}$ and the observed collinearity distribution in the variable, $\cos\theta = -(\vec{p}_e \cdot \vec{p}_\mu)/|p_e|\cdot|p_\mu|$ are consistent with the calculations based on the assumption that the τ is a spin 1/2 lepton with V-A coupling. But this does not necessarily exclude higher half-integer spin assignments of τ such as spin 3/2.

Alles and Borelli[4] considered the production of τ and some of us[5] also studied the decay distribution in addition to the production under the assumption of τ being a spin 3/2 object. The cross section $\sigma_{e\mu}$ calculated under the assumption of the τ being a spin 3/2 object was shown to be consistent[6] with experiment. The collinearity angle distribution for the spin 3/2 case was almost identical to the spin 1/2 case up to 6 GeV of E_{cm} where E_{cm} is the center of mass energy of e^+e^-. Above 6 GeV, there were some differences between the spin 1/2 case and spin 3/2 case. But, the present data is consistent with both assumptions within the statistical significance of the data. However, it is expected that the angular distribution of e or μ from the leptonic decay of τ should show some difference between the spin 3/2 assumption and spin 1/2 assumption of τ. But no data is available at present. More readily available experimental data are, perhaps, the branching ratios of the τ decay where the difference between spin 3/2 assumption and spin 1/2 assumption should appear. Preliminary results of the experimental branching ratios of τ were reported[7] recently as shown in Table 1.

The observed rates of the decay modes, $\tau \to \rho\nu$ and $\tau \to A_1\nu$ are in agreement with the calculation, for example, of Y. S. Tsai[8], with the spin 1/2 assignment of the heavy lepton. Although it is very preliminary, the pionic mode, $\tau \to \pi\nu$, is absent which should be about the same strength as $\tau \to A_1\nu$ under the spin 1/2 assumption of τ.

The purpose of this paper is to present a possible way of explaining the absence of the pionic mode leaving other observed decay modes, $\tau \to \ell + \nu_\tau + \bar{\nu}_\ell$, $\tau \to \rho\nu$ and $\tau \to A_1\nu$ intact. We choose to compute the relative branching ratios

$$R_\pi = \frac{\Gamma(\tau \to \pi\nu)}{\Gamma(\tau \to e\bar{\nu}\nu)} \quad , \quad R_\rho = \frac{\Gamma(\tau \to \rho\nu)}{\Gamma(\tau \to e\bar{\nu}\nu)} \text{ and } R_{A_1} = \frac{\Gamma(\tau \to A_1\nu)}{\Gamma(\tau \to e\bar{\nu}\nu)}$$

For the purpose of calculation, we use Rarita-Schwinger formalism for the spin 3/2 object. Although the formalism has some theoretical difficulties such as unrenormalizability, we shall ignore the problem for the purpose of phenomenological comparison with the data.

If one assumes the conventional V-A type interaction, the simplest matrix elements[9] for the decays, $\tau \to e\bar{\nu}\nu$, $\tau \to \pi\nu$, $\tau \to \rho\nu$ and $\tau \to A_1\nu$ are

$$M_{fi}^{e} = \frac{G}{\sqrt{2}} \bar{u}(e)\gamma^{\mu}(1-\gamma_5)\ V(\nu_e)\bar{u}(\nu_\tau)(1+\gamma_5)u_\mu(\tau)$$

$$M_{fi}^{\pi} = \frac{G}{\sqrt{2}} f_\pi \cos\theta_c q_\mu^\pi \bar{u}(\nu_\tau)(1+\gamma_5)u^\mu(\tau)$$

$$M_{fi}^{\rho} = \frac{G}{\sqrt{2}} f_\rho\ \cos\theta_c \epsilon_\mu \bar{u}(\nu_\tau)(1+\gamma_5)u^\mu(\tau)$$

$$M_{fi}^{A} = \frac{G}{\sqrt{2}} f_A \cos\theta_c \epsilon_\mu \bar{u}(\nu_\tau)(1+\gamma_5)u^\mu(\tau)$$

where u and v are the spinor of spin 1/2, u_μ is Rarita-Schwinger spinor of τ, and ε_μ is the polarization vector of the spin 1 particle. The coupling constant f_π is well known and we can obtain f_ρ by $e^+ e^- \to \rho$ via C.V.C. f_A can be obtained via the Weinberg sum rule from f_ρ as others have done[8]. The straightforward calculation gives then

$$\Gamma(\tau \to e\bar{\nu}\nu) = \frac{G^2M^5}{960\pi^3}$$

$$\Gamma(\tau \to \pi\nu) = \frac{G^2\cos^2\theta_c}{192\pi} f_\pi^2 M^3(1-X_\pi^2)^4$$

$$\Gamma(\tau \to \rho\,\nu) = \frac{G^2\cos^2\theta_c}{768\pi^2} M_\rho^2 M^3(1-X_\rho^2)^2(1+10X_\rho^2+X_\rho^4)$$

$$\Gamma(\tau \to A_1\nu) = \frac{G^2\cos^2\theta_c}{3072\pi^2} M_A^2 M^3(1-X_A^2)^2(1+10X_A^2+X_A^4)$$

where M is the heavy lepton mass, χ_α is $(\frac{m_\alpha}{M})$ for $\alpha = \pi$, ρ and A_1, respectively.

We wish to point out that, as in the case of the spin 1/2, our calculation of R_π is reliable since there are no unknown parameters once we assume the conventional form of the interaction. The results of our calculation and the corresponding values of spin 1/2 assignment are given in Table 1.

It should be pointed out that the relative supression of the pionic mode to $\tau \to \rho\nu$ and $\tau \to A_1\nu$ comes out very naturally in the spin 3/2 assumption due to the p-wave nature of $\tau \to \pi\nu$. This angular momentum barrier suppression is absent in the spin 1/2 model.

We conclude by remarking that if the pionic mode can be observed at the level predicted by the spin 1/2 assumption, it is good evidence against the spin assignment of (3/2, 1/2) where 3/2 refers to the spin of τ and 1/2 refers to the spin of ν_τ. But should the absence of the pionic mode persist, a further investigation is necessary including the spin 3/2 assignment of τ.

Acknowledgment

The authors wish to express their sincere gratitude to Professor C. W. Kim for suggesting this problem to them. One of them (J. K.) thanks the Department of Physics, The Johns Hopkins University for its hospitality, and another author (H.S.) wishes to thank Professor J. D. Bjorken and Professor S. Drell for the hospitality at S.L.A.C.

Table 1

The branching ratios of heavy lepton

The mode	experiment	Computed value of 3/2 case	Computed value[(a)] of 1/2 case
$\frac{\Gamma(\tau\to e\bar{\nu}\nu)}{\Gamma(\tau\to \text{all})}$	0.18 ± 0.04 [a)]	0.19*	0.20
$\frac{\Gamma(\tau\to\pi\nu)}{\Gamma(\tau\to \text{all})}$	not seen[(11)]	0.04	0.11
$\frac{\Gamma(\tau\to\rho\nu)}{\Gamma(\tau\to \text{all})}$	0.24 ± 0.09 [b)]	0.21	0.22
$\frac{\Gamma(\tau\to A_1\nu)}{\Gamma(\tau\to \text{all})}$	0.11 ± 0.4 ± 0.3 [c)]	0.11	0.07

a) Value reported by M. Perl in SLAC-Pub. 2022.

b) Value quoted by M. Perl of DASP data.

c) Value quoted by M. Perl of Pluto data.

*The value obtained in ref.(5) by fitting $\sigma_{e\mu}$ using calculated $\sigma_{\tau\tau}^{3/2}(s)$ instead of $\sigma_{\tau\tau}^{1/2}(s)$. Our model calculation for $\frac{\Gamma(\tau\to e\bar{\nu}\nu)}{\Gamma(\tau\to \text{all})}$ was 0.21 ~ 0.16[(10)]

References

1. M. L. Perl et al., Phys. Rev. Letters 35, 1489(1975); Phys. Letters 63B, (1976)466.

2. H. Meyer in Proceedings of the Orbis Scientia - 1977 (Coral Gables, 1977); V. Blobel in Proceedings of the XII Recontre de Moriond (Flaine, 1977).

3. M. Perl in the Proceedings of the XII Recontre de Moriond (Flaine, 1977).

4. W. Alles and V. Allen Borelli, Nuovo Cimento 35, (1976)125.

5. Jewan Kim, Insoo Ko and H. S. Song, to be published.

6. The amplitude $T(e^+e^- \to \tau^+\tau^-) = F(q^2)\,\frac{e^2}{q^2}\,\bar{v}(k')\gamma_\mu u(k)\;\bar{u}_\alpha(p)\gamma_\mu v_\alpha(p')$ was used to calculate $\sigma^{3/2}_{\tau.\tau}(s)$ in ref. (5) where a simple minimal coupling was assumed.

   u, v, u_α and v_α are the Dirac spinors for electron, positron, the Rarita-Schwinger spinor for τ^+ and τ^-, respectively.

   The form factor

   $$F(q^2) = \frac{1}{(1 - q^2/m^2)^2}$$

   was introduced in order to accommodate the possibility that the heavy lepton may be composite. A good fit was obtained with $m^2 = 50\ \text{GeV}^2$.

7. M. Perl in Proceedings of Benjamin Lee Memorial International Conference at N. A. L. (1977).

8. Y. S. Tsai; Phys. Rev. D4, (1971)282.

9. The dipole form factor used in ref. (5) was $F(q^2) = \frac{1}{(1 - \frac{q^2}{m^2})^2}$ with $m^2 = 50\ \text{GeV}^2$.

   Our range of q^2 is at most $0 \sim 4\ \text{GeV}^2$ for $\tau \to e\bar{\nu}\nu$ and much narrower for two body decays. We have ignored the effect of the form factor since the values of q^2 are much smaller than $m^2 = 50\ \text{GeV}^2$. In addition, there should

9. (continued) be effective cancellation in the branching ratios. Therefore, we have computed the branching ratios as if τ is a point particle. The error by doing so should not affect our conclusion.

10. The estimate of $\Gamma(\tau \to \nu +$ hadron continuum) depends on the cross section $\sigma(e^+e^- \to$ hadrons) in I = 1 channel as pointed out in ref. (8). Our model calculation reflects the range of values we used for $\sigma(e^+e^- \to$ hadrons). However, our result has no direct connection to this uncertainty because we use the fitted leptonic branching ratio to obtain R_π, R_ρ and R_{A_1}.

11. $B_e B_\pi = 0.004 \pm 0.005$ was quoted of DASP data in SLAC-pub-2022 (in pionic branching ratio, it corresponds to 0.02 ± 0.025). This result is consistent with the absence of the pionic mode or our model.