

RECENT RESULTS FROM SPEAR\*

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ABSTRACT: Recent results from SPEAR include measurements of Cabibbo-suppressed decay modes of the  $\tau$  (Mark II), and a limit on the decay  $J/\psi \rightarrow \gamma + \text{axion}$  (Crystal Ball).

INTRODUCTION

The experimental program at SPEAR continues to be a productive one. The Crystal Ball experiment<sup>1</sup> is still accumulating data at SPEAR; this past year was devoted to doubling the  $J/\psi$  and  $\psi'$  data sets and to taking more data at  $5.2 < E_{c.m.} < 7.4$  GeV. The Mark II detector<sup>1</sup> was moved to PEP in the summer of 1979, but the SPEAR data continues to be investigated. In this report I will concentrate on the observation of the Cabibbo-suppressed decay  $\tau \rightarrow K\nu_\tau$  by the Mark II, and the search for the radiative decay  $J/\psi \rightarrow \gamma + \text{axion}$  with the Crystal Ball. Other recent results from SPEAR include the analysis of  $f^0$ ,  $A_2$ , and  $\rho^0\rho^0$  production in two photon interactions (Crystal Ball and Mark II),<sup>2</sup> and a quark search by the Mark II.<sup>3</sup>

THE CABIBBO-SUPPRESSED DECAY  $\tau \rightarrow K\nu_\tau$

Since the discovery of the  $\tau$ , a great deal has been learned, all supporting the notion that the  $\tau$  is a new sequential lepton which decays according to the standard weak interaction theory with V-A coupling. Recently, the Mark II has observed<sup>4</sup> a Cabibbo-suppressed decay of the  $\tau$ ,  $\tau \rightarrow K^*(890)\nu_\tau$ , which proceeds via the weak hadronic vector current. This decay has a rate of order  $\tan^2\theta_C$  times the non-suppressed decay  $\tau \rightarrow \rho\nu_\tau$ , as expected in the standard picture. Here, I will discuss the new observation, also by the Mark II, of the decay  $\tau \rightarrow K\nu_\tau$ , which probes the weak hadronic axial-vector current. This is the Cabibbo-suppressed analog of the decay  $\tau \rightarrow \pi\nu_\tau$ , hence, the relative rates are predicted<sup>5</sup> to be of order  $\tan^2\theta_C$ :

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$$\frac{\Gamma(\tau \rightarrow K\nu_\tau)}{\Gamma(\tau \rightarrow \pi\nu_\tau)} = \tan^2\theta_C \left[ \frac{1 - (m_K/m_\tau)^2}{1 - (m_\pi/m_\tau)^2} \right]^2 \quad (1)$$

The search for the decay  $\tau \rightarrow K\nu_\tau$  proceeds by requiring one of the produced  $\tau$ 's to decay leptonically. Thus, one looks for events of the form:

$$e^+e^- \rightarrow \tau^+\tau^- \quad (\text{and charge conjugate})$$

$$\begin{array}{l} \swarrow \\ \rightarrow K^-\nu_\tau \\ \searrow \\ \rightarrow \ell^+\nu_\ell\bar{\nu}_\tau \quad (\ell = e \text{ or } \mu) \end{array}$$

The data set available for the search contains approximately 47,000 produced  $\tau\bar{\tau}$  pairs in  $17 \text{ pb}^{-1}$  of data at  $3.8 < E_{\text{c.m.}} < 6.7 \text{ GeV}$ . Briefly, the cuts to select the desired events are as follows:

- 1) The event must contain exactly one positive and one negative charged particle, with no photons observed (with  $E_\gamma > 100 \text{ MeV}$ ) in the liquid Argon shower counters.
- 2) The event must contain missing neutrals (i.e., neutrinos) by requiring  $\theta_{\text{acoplanarity}} > 20^\circ$ .
- 3) One of the charged particles must be identified as a lepton ( $e^\pm$ : in liquid Argon counter,  $E_e > 400 \text{ MeV}$ ;  $\mu^\pm$ : in muon system,  $E_\mu > 700 \text{ MeV}$ ).
- 4) Cosmic rays are suppressed with the time-of-flight (TOF) counters.
- 5) Beam-gas backgrounds are suppressed by the vertex cuts:  
 $|z_{\text{vtx}}| < 10 \text{ cm}$ ;  $|z_{\text{vtx}}(\text{track 1}) - z_{\text{vtx}}(\text{track 2})| < 10 \text{ cm}$ .
- 6) Events with  $(\text{TOF mass})^2 > 0.1 \text{ GeV}^2$  are hand scanned, and eliminated if there is evidence for additional (missed) charged tracks.
- 7) After a study of the  $(\text{TOF mass})^2$  versus momentum scatter plot (Fig. 1), the following cuts are made:
  - a)  $\text{TOF}(\text{measured}) - \text{TOF}(\text{expected for } \pi) > 4.0 \text{ standard deviations}$ .
  - b)  $(\text{TOF mass})^2 < 0.6 \text{ GeV}^2$ .
  - c)  $\text{TOF}(\text{measured}) - \text{TOF}(\text{expected for } p) > 2.0 \text{ standard deviations}$ .

The time-of-flight analysis is crucial to the selection of K events, so deserves further discussion. A key issue is how large the contribution from the tails of the TOF distribution for the  $\pi$ 's is. The observed TOF distribution is Gaussian to a very good approximation, with a small tail to larger TOF, which is accounted for in the results obtained.

Table I shows the  $\tau \rightarrow K\nu_\tau$  branching ratio measured as a function of the TOF cut used. The contribution from the most significant physics background,  $\tau \rightarrow K^*\nu_\tau$  decays where the gammas from the  $\pi^0$  from the  $K^* \rightarrow K\pi^0$  decay are not observed in the detector, is also indicated in the table. The fact that the branching ratio obtained is independent of the position of the TOF cut is evidence that the backgrounds are understood.

Table I  
BRANCHING RATIO FOR  $\tau \rightarrow K\nu_\tau$  AS A FUNCTION OF THE TOF CUT (MARK II)

$\frac{\text{TOF Cut} - \text{TOF}_\pi}{\sigma\text{TOF}_\pi}$	$l^\pm K^\mp$ Candi- dates	$\pi$ Contami- nation	$\tau \rightarrow K^* \nu_\tau$ Back- ground	Effi- ciency (%)	$B(\tau \rightarrow K\nu_\tau)^*$ (%)
>3.0	31	$10.2 \pm 1.3$	$3.2 \pm 1.3$	$3.8 \pm 0.2$	$1.4 \pm 0.4 \pm 0.3$
>3.5	20	$4.8 \pm 0.7$	$2.8 \pm 1.2$	$3.1 \pm 0.2$	$1.3 \pm 0.4 \pm 0.3$
>4.0	15	$3.0 \pm 0.6$	$2.5 \pm 1.0$	$2.6 \pm 0.1$	$1.2 \pm 0.4 \pm 0.2$
>4.5	13	$1.9 \pm 0.6$	$2.1 \pm 0.9$	$2.2 \pm 0.1$	$1.3 \pm 0.5 \pm 0.3$
>5.0	12	$0.3 \pm 0.6$	$2.0 \pm 0.8$	$1.8 \pm 0.1$	$1.7 \pm 0.6 \pm 0.3$

\*First error is statistical, second is systematic.

The final result quoted by the Mark II collaboration is that  $B.R.(\tau \rightarrow K\nu_\tau) = (1.2 \pm 0.4 \pm 0.2)\%$ . This result is compatible with the predicted value of 0.7%, from equation 1 and Mark II measurement of the  $\tau \rightarrow \pi\nu_\tau$  decay.<sup>4</sup>

#### SEARCH FOR THE DECAY $J/\psi \rightarrow \gamma + \text{AXION}$

It has been pointed out<sup>6</sup> that if one scheme proposed to salvage strong P and T conservation<sup>7</sup> is correct, then there should exist a light, semi-weakly interacting pseudoscalar boson called the axion. Some fairly definite predictions can be made for the properties of this particle, in particular, it should be produced in radiative decays of the  $J/\psi$  with the branching ratio:

$$\begin{aligned}
 B.R.(J/\psi \rightarrow \gamma a) &= \frac{G_F}{\sqrt{2}} \frac{m_c^2}{\pi \alpha} x^2 B.R.(J/\psi \rightarrow e^+e^-) \\
 &\cong 5 \times 10^{-5} x^2 (m_c/1.4 \text{ GeV})^2 \quad (2)
 \end{aligned}$$

The quantity "x", the ratio of the vacuum expectation values of the two Higgs fields in the theory, is sometimes set equal to one according to

theoretical prejudice because there is no known reason why it should be different, than one. However, without more compelling theoretical reasoning,  $x$  must be considered a free parameter.

Motivated by the possible existence of an axion, the Crystal Ball experiment has conducted a search for radiative decays of the  $J/\psi$  to axion-like objects, i.e., particles with the following properties:

- 1) Low-mass ( $m_a \lesssim 500$  MeV). The requirement is imposed by the requirement that the radiative photon be consistent with beam energy.
- 2) Long-lived ( $\tau_a > 2 \times 10^{-12} \times m_a$  (MeV) seconds). This is required to insure that the particle passes through the Crystal Ball detector before decaying.
- 3) Not highly interacting. The particle must pass through the detector ( $\sim 40$  cm of NaI) without leaving a trace.

The search reported here is based on a data sample corresponding to  $1.25 \times 10^6$  ( $\pm 5\%$ )  $J/\psi$  decays.

The cuts on the data are designed to select events which contain exactly one "clean" photon:

- a) Event must consist of one neutral and no charged particles.
- b) The event must be in time with the  $e^+e^-$  beam cross.
- c) The photon candidate must be within the solid angle covered by the proportional chambers ( $|\cos\theta| < 0.8$ ).
- d) The photon candidate must exhibit a lateral shower pattern in the NaI which is compatible with that deposited by a single electromagnetically showering particle.

With the above cuts, Fig. 2 shows the events remaining on a scatter-plot of the cosine of the zenith angle ( $\cos Z$ ) of the photon versus the photon energy. It can be seen that there is a general background of events, especially near the top of the ball and for energies less than  $E_{\text{beam}}$  (trigger thresholds reduce the efficiency for energies  $\lesssim 1$  GeV). This angular distribution may be interpreted as due to photons and electrons of cosmic ray origin. The effect of this background is greatly reduced by accepting only those photons which enter the lower hemisphere of the Crystal Ball. Finally, a cut on  $1440 < E_\gamma < 1640$  MeV to select those photons which are near beam energy is made. The overall efficiency has been determined to be 26% in studies of Monte Carlo calculations and of real data.

The final number of events in the signal region (Fig. 2) is 5 events. The expected background is estimated to be 2.5 events by using events which are not in-time with the  $e^+e^-$  beam crossing. Thus, there is no significant signal above background and the upper limit

$$\text{B.R.}(J/\psi \rightarrow \gamma + \text{axion}) < 3 \times 10^{-5} \text{ 90\% C.L.}$$

is obtained.

For a charmed quark mass of  $\geq 1.4$  GeV, this limit already implies that the parameter  $x$  is less than 1 [Eq. (2)]. Because the decay  $T \rightarrow \gamma a$  has a different dependence on  $x$ , the combination of this  $J/\psi \rightarrow \gamma a$  limit, and a parallel (and experimentally feasible) search for  $T \rightarrow \gamma a$  can provide an  $x$ -independent test of the standard axion model.<sup>8</sup>

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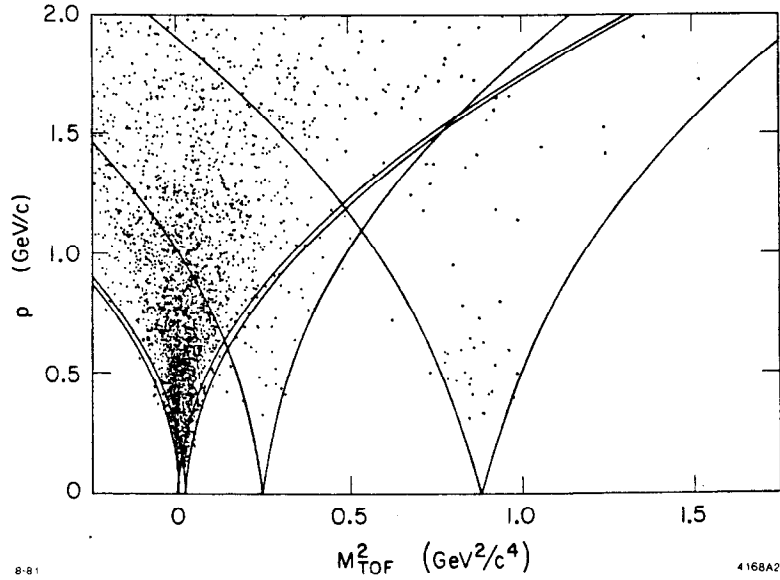


Fig. 1. Scatterplot of momentum versus (TOF mass)<sup>2</sup> for lepton-tagged events (see text for selection). The contours indicate 3 $\sigma$  deviations for  $e$  and  $\pi$ , 2 $\sigma$  for  $K$  and  $p$ .

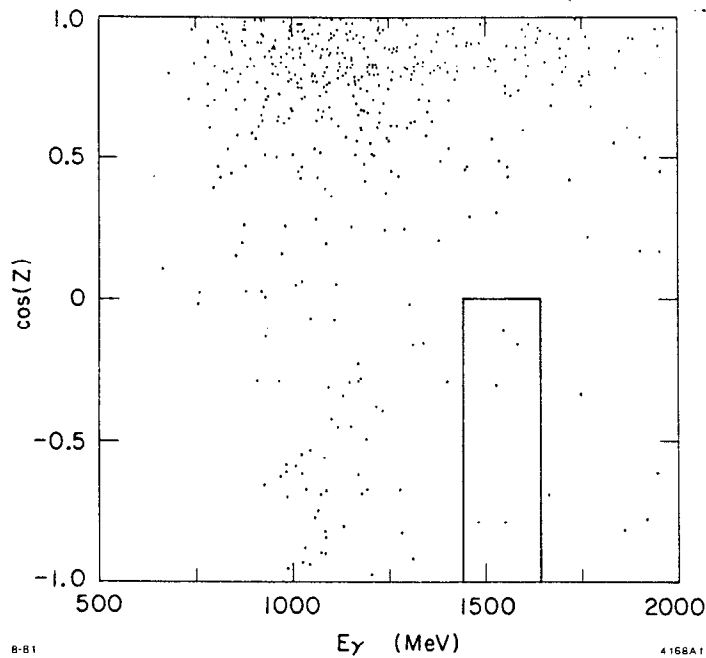


Fig. 2. Scatterplot showing the cosine of the zenith angle versus photon energy for single photon plus no charged particle candidate events at the  $J/\psi$  resonance. The boxed region shows the area used in the search for  $J/\psi \rightarrow \gamma + \text{axion}$  decays.