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MEASUREMENT OF THE BRANCHING RATIO AND POLARIZATION FOR $J/\psi \to \gamma f(1270)$*

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ABSTRACT

The decay $J/\psi \to \gamma f(1270)$, $f(1270) \to \pi^o\pi^o$ has been studied. The γf decay branching ratio is measured to be $(1.48 \pm 0.25 \pm 0.30) \times 10^{-3}$. A fit to the f production and decay angular distributions yields the values $A_1/A_0 = 0.88 \pm 0.13$ and $A_2/A_0 = 0.04 \pm 0.19$, where A_λ are the f helicity amplitudes. These results disagree with the values predicted from a QCD two-gluon-exchange model.

Zweig-suppressed radiative decays of heavy vector mesons to tensor mesons are expected to proceed via a two-gluon intermediate state in lowest order in QCD. A nonrelativistic QCD calculation[1] finds the polarization of the tensor meson to be a function of the ratio of the tensor meson mass to the vector meson mass. We report on measurements of the branching ratio and polarization for the decay $J/\psi \to \gamma f(1270)$.

The data were collected with the Crystal Ball detector at the SLAC e^+e^- storage ring facility SPEAR at the peak of the $J/\psi(3095)$ resonance. The detector, event trigger, and data reduction have been described in detail elsewhere.[2] The relevant parameters are summarized here. The detector consists primarily of a segmented array of NaI(Tℓ) crystals for high resolution measurements of the energy and position of electromagnetic showers. The photon energy resolution is $\sigma_E/E = 2.6\% / E^{1/4}$ (E in GeV) and the photon angular resolution is 1-2 degrees. The solid angle coverage of the main array is 93% of 4π sr and is extended to 98% with crystals in the endcap regions. The beam pipe is surrounded by magnetostrictive spark chambers and multiwire proportional chambers for charged particle tagging and tracking. The innermost spark chamber layer covers 94% of the solid angle.

This analysis is based on a sample of 2.2×10^6 produced J/ψ events. We have studied the decay

$$J/\psi \to \gamma\pi^0\pi^0 \quad . \qquad (1)$$

In nearly all decays (1), one or both π^0's is sufficiently energetic that the two γ's from the π^0 decay produce showers which overlap in the NaI and hence the π^0 is identified as a single neutral particle. In general, for events with $\pi^0\pi^0$ invariant mass near the mass of the f(1270), only one of the π^o's suffers from this overlap problem. Hence, each event is required to have four neutrals with observed energy greater than 10 MeV. Photons are identified by energy deposits in clusters of several adjacent crystals. Photon directions are determined from the positions in space of the shower centers relative to the interaction point. Neutral pions which decay into γ's with showers which overlap are identified by the lateral shower distributions.[3] Tracks tagged by the chambers are rejected as charged. To enhance charged particle tagging efficiency, we require $|\cos\theta_\gamma| < 0.9$ for each γ, where θ_γ is the polar angle of the γ with respect to the beam axis. In order to avoid problems with overlapping showers, we require $\cos\theta_{\gamma\gamma} < 0.9$, where $\theta_{\gamma\gamma}$ is the angle between any two photons. (This requirement is not imposed in the case of pairs of γ's from a single π^o which produce showers which overlap.)

Figure 1 shows the $\pi^o\pi^o$ invariant mass distribution for events which satisfy 4-constraint fits[4] to the hypothesis

$$J/\psi \to \gamma\pi_1^o\pi_2^o \quad , \quad \pi_1^o \to \gamma\gamma \tag{2}$$

with $\chi^2 < 20$, where the γ's from π_2^o form a single neutral cluster. The f(1270) is clearly observed in this distribution. A fit to this mass distribution with a relativistic Breit-Wigner resonance plus a polynomial background yields 178 ± 30 resonance events. We obtain the following resonance parameters for the f: $M = 1260 \pm 15$ MeV and $\Gamma = 170 \pm 40$ MeV. The errors include estimated systematic uncertainties. These parameters agree with the standard values.[5]

The detection efficiency for (2) was determined to be 0.20 by Monte Carlo calculation. From this and the number of observed f events, the branching ratio for $J/\psi \rightarrow \gamma f$ is calculated to be[6] $B(J/\psi \rightarrow \gamma f) = (1.48 \pm 0.25 \pm 0.30) \times 10^{-3}$. The first error is statistical and the second is the estimated systematic uncertainty. This result is in agreement with previously published results.[7]

The helicity amplitudes for the process $J/\psi \rightarrow \gamma f$ were determined by a maximum likelihood fit to the 3-dimensional decay angular distribution[8]

$$
\begin{aligned}
W(\theta_\gamma,\theta_\pi,\phi_\pi) = {} & 3x^2 \sin^2\theta_\gamma \sin^2 2\theta_\pi \\
& + \left(1+\cos^2\theta_\gamma\right)\left[\left(3\cos^2\theta_\pi - 1\right)^2 + \frac{3}{2}\, y^2 \sin^4\theta_\pi\right] \\
& + \sqrt{3}\, x \sin 2\theta_\gamma \sin 2\theta_\pi \left[3\cos^2\theta_\pi - 1 - \frac{1}{2}\sqrt{6}\, y \sin^2\theta_\pi\right]\cos\phi_\pi \\
& + \sqrt{6}\, y \sin^2\theta_\gamma \sin^2\theta_\pi \left(3\cos^2\theta_\pi - 1\right)\cos 2\phi_\pi \qquad ,
\end{aligned}
$$

where $x = A_1/A_0$, $y = A_2/A_0$, and A_λ are the f helicity amplitudes. θ_γ is the polar angle of the direct photon and (θ_π,ϕ_π) are the polar and azimuthal angles of one of the π's with respect to the γ direction in the f rest frame. $\phi_\pi = 0$ is defined by the electron beam direction. Only events with $\pi^o\pi^o$ invariant mass between 1150 and 1400 MeV were used in the fit. The contamination from background events is expected to be less than 20% in this mass region. Figure 2 shows contours of equal probability as a function of x and y. The data point is the best fit value: $x = 0.88 \pm 0.11$ and $y = 0.04 \pm 0.14$, where the errors are statistical only. Systematic errors arise from uncertainties in the angular distribution of background events. These errors were estimated by fitting the angular distribution for samples of events which included background events from outside the 1150 to 1400 MeV mass region. Inclusion of these estimated systematic errors gives $x = 0.88 \pm 0.13$ and $y = 0.04 \pm 0.19$. These results are in agreement with previously published PLUTO results,[9] $x = 0.6 \pm 0.3$ and $y = 0.3^{+0.6}_{-1.6}$, and preliminary results from the Mark II.[10]

The errors on our measurements are small enough that a quantitative comparison with theory can be made. Theoretical predictions for pure M2 and E3 transitions (E1 is off scale), QCD,[1] and tensor meson dominance (TMD)[11] are also shown in Fig. 2. All of these predictions are inconsistent with the experimental measurement. In particular, the QCD calculation based on two-gluon exchange[1] is more than three standard deviations from the experimental point. Figure 3 shows the $|\cos\theta_\gamma|$ and $|\cos\theta_{\pi^0}|$ projections along with curves for our best fit (solid curve) and QCD (dashed curve). The discrepancy between the data and the QCD prediction is clearly seen in the $|\cos\theta_{\pi^0}|$ projection. However, it should be noted that the QCD calculation involves non-relativistic approximations and assumes that the intermediate gluons are on the mass shell. This might account for the discrepancy with experiment.

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3. Single γ's can be separated from π^{o}'s by analysis of the lateral shower distribution up to energies of approximately 1.5 GeV.

4. One constraint is removed in the determination of the vertex position along the beam direction which cannot otherwise be determined for an all neutral event. The additional constraint is the π^{o} mass constraint for the π^{o} which is observed to decay into two distinct γ's.

5. Particle Data Group, Rev. Mod. Phys. 52, S1 (1980) and references therein.

6. $B(f \rightarrow \pi\pi) = 0.831$ and $B(f \rightarrow \pi^{+}\pi^{-})/B(f \rightarrow \pi^{o}\pi^{o}) = 2$ are assumed.

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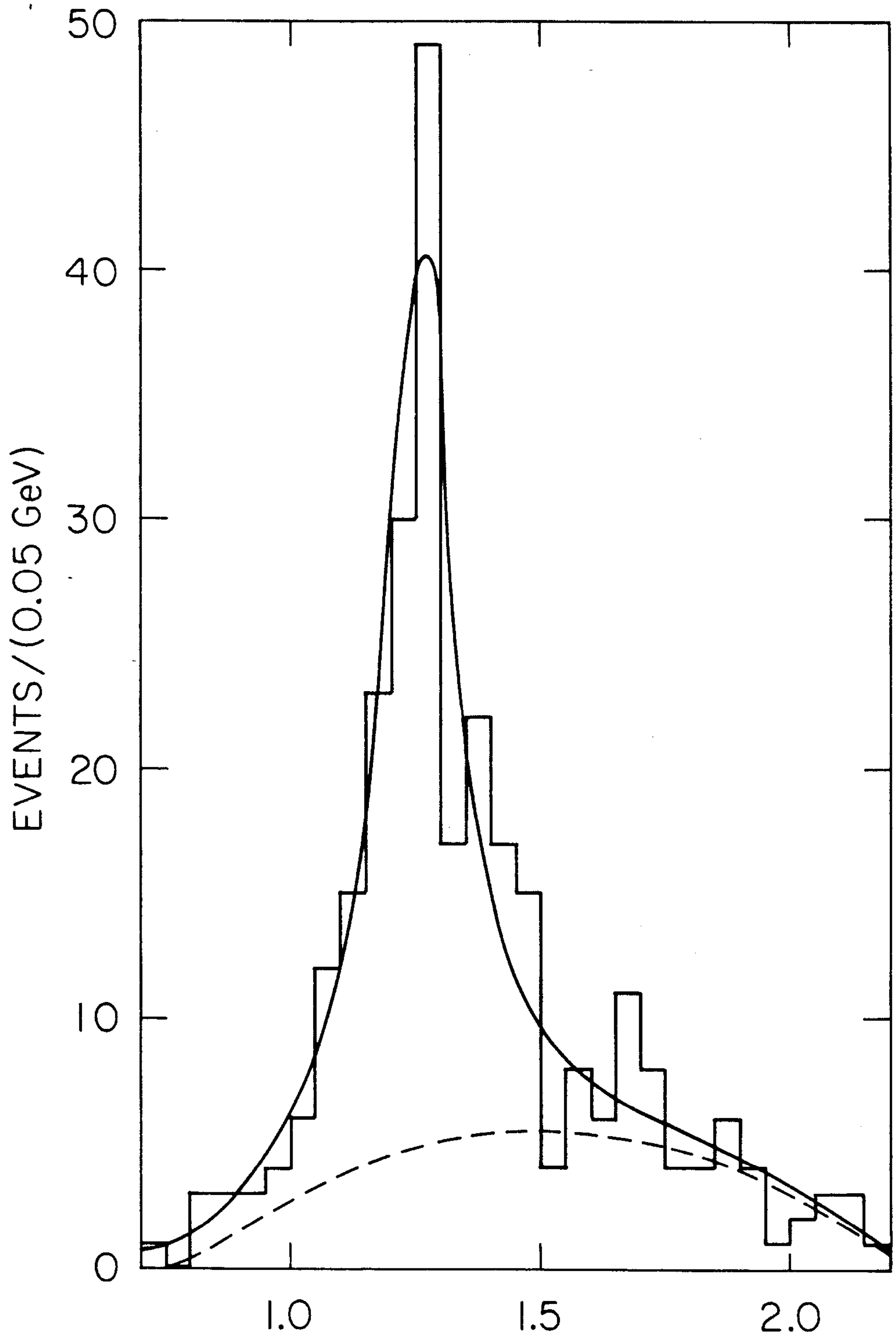
FIGURE CAPTIONS

Fig. 1. $\pi^o\pi^o$ invariant mass distribution. Solid curve represents best fit to distribution. Dashed curve represents background contribution.

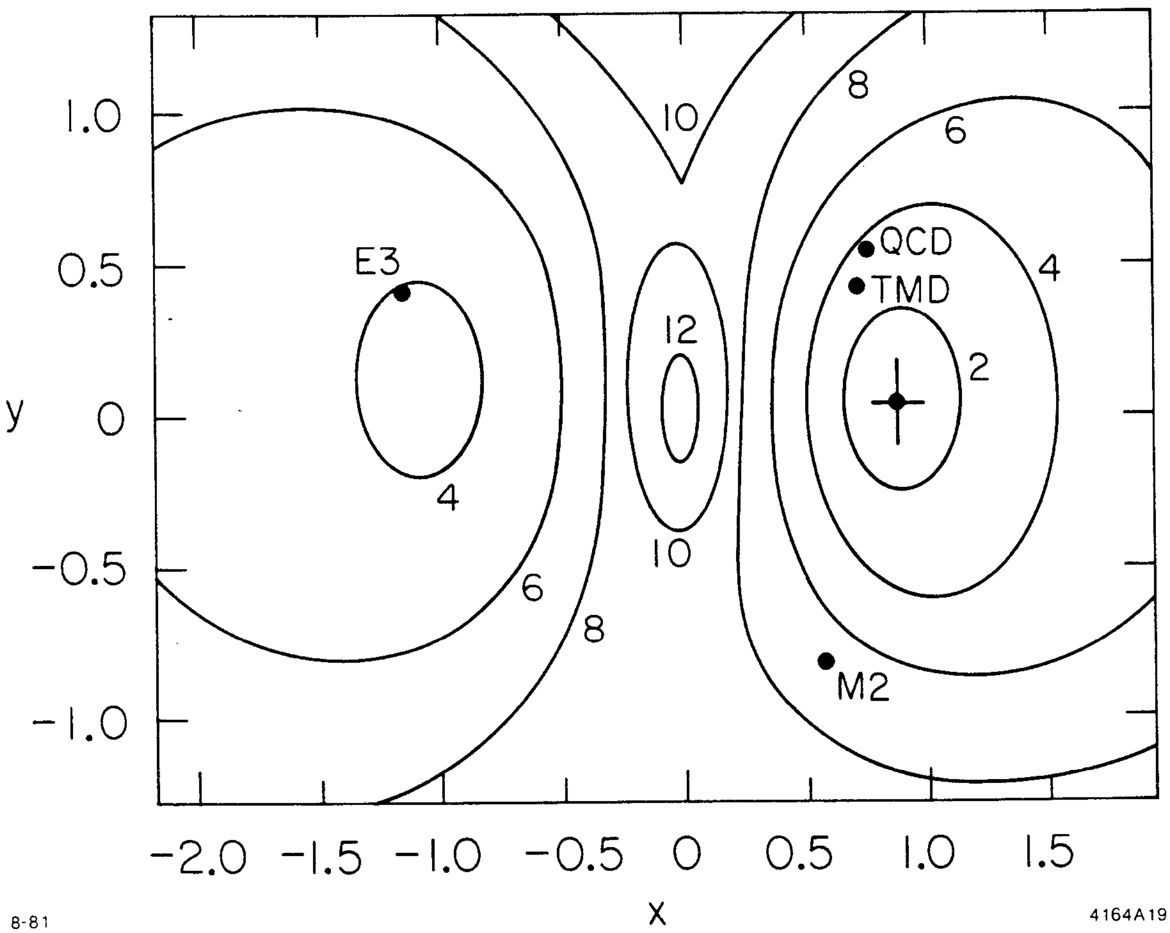
Fig. 2. Contours of equal probability as a function of x and y. Data point with error bars represents measurement. Other points are theoretical predictions. Numbers next to curves are in units of standard deviations.

Fig. 3. (a) $|\cos\theta_\gamma|$ and (b) $|\cos\theta_{\pi^o}|$ distributions for $J/\psi \to \gamma f$, $f \to \pi^o\pi^o$. Solid curves are best fit distributions for spin 2. Dashed curves are expectations from QCD.



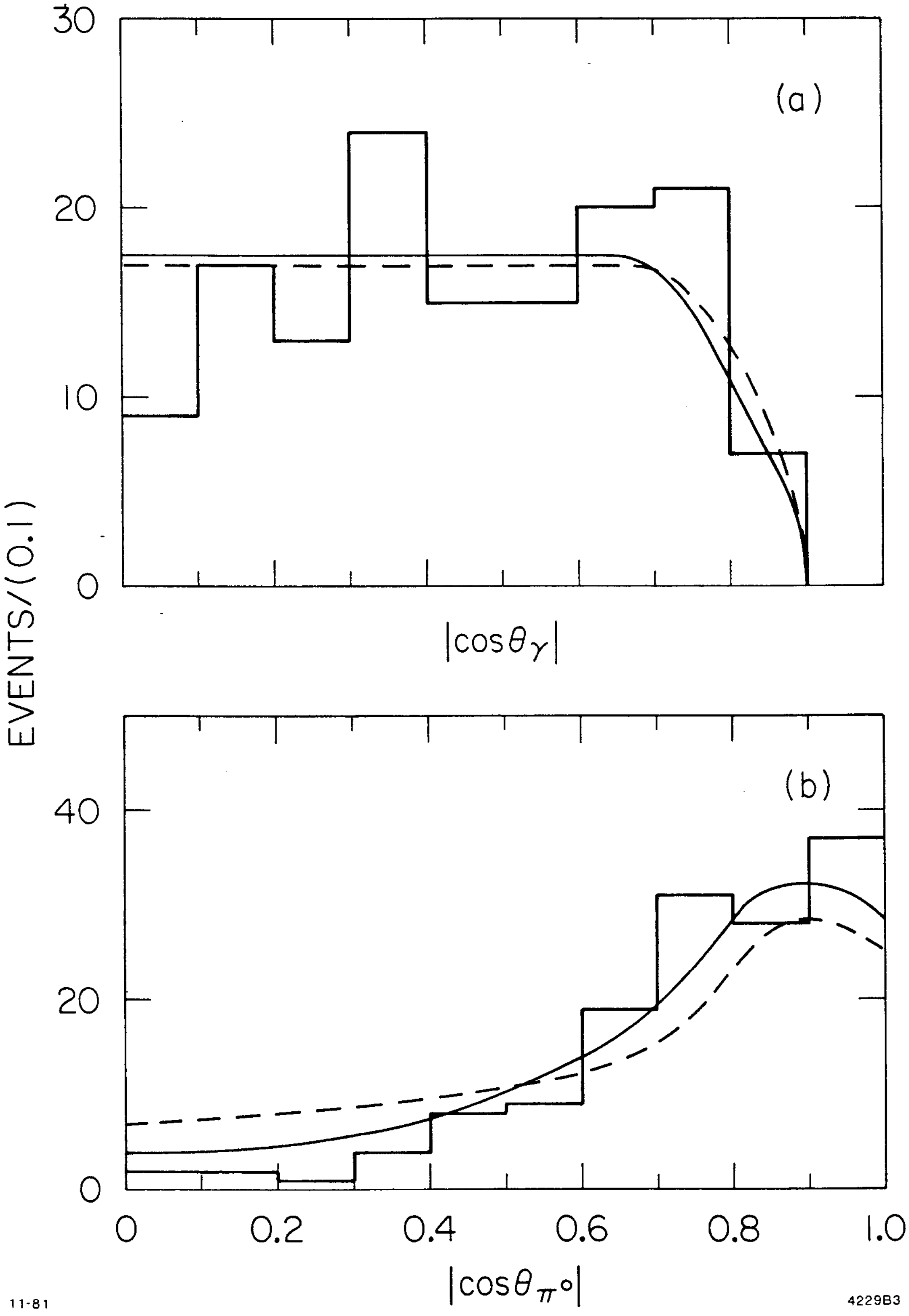
50
40
30
20
10
0
EVENTS/(0.05 GeV)
1.0
1.5
2.0
$M_{\pi^\circ\pi^\circ}$ (GeV)
8-81
4164B15

Fig. 1



1.0
0.5
y
0
−0.5
−1.0
−2.0
−1.5
−1.0
−0.5
0
0.5
1.0
1.5
x
10
8
6
QCD
TMD
4
E3
12
2
4
10
6
8
M2
8-81
4164A19

Fig. 2



30
20
10
0
(a)
$|\cos\theta_\gamma|$
EVENTS/(0.1)
40
20
0
(b)
0
0.2
0.4
0.6
0.8
1.0
$|\cos\theta_{\pi^0}|$
11-81
4229B3

Fig. 3