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Study of ψ' Decays*

Walter H. Toki
representing the Mark III Collaboration
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94309

Abstract

Hadronic decays of the ψ' are reviewed and a new preliminary upper limit of $B(\psi'\to\rho\pi)<7.0\times10^{-5}$ at 90% C.L. from the Mark III is presented.

The ψ' is the 2^3S_1 $c\bar{c}$ quark-antiquark vector meson and is the only well established radial excitation. The hadronic decay rate of the ψ' relative to the J/ψ should scale as the ratio of the three gluon widths which are proportional to the leptonic widths divided by the full widths;

$$\frac{B(\psi'\to \text{hadrons})}{B(J/\psi\to \text{hadrons})}=\frac{B(\psi'\to ggg)}{B(J/\psi\to ggg)}=\frac{\Gamma\left(\psi'\to e^+e^-\right)\Gamma(J/\psi)}{\Gamma\left(J/\psi\to e^+e^-\right)\Gamma(\psi')}=(12.2\pm2.4)\%$$

This predicts that the absolute branching ratios of hadronic modes of the ψ' are 12% of the corresponding decay from the J/ψ or 8 times smaller. The Mark II group[1] measured several decays in 1982 and observed hadronic decays into several multibody decays but none of the vector-pseudoscalar pair combinations. More recently, the Crystal Ball group[2] observed the radiative decay to the tensor f(1270) but neither to the η nor the η'. The measured rates are shown in table 1. The second column contains the J/ψ branching rates and the third column the ratio of rates which should be ~12%. The results are very striking. Within the errors, the missing modes are vector pseudoscalar decays whereas the other modes are roughly consistent with the factor of 8 ratio. For some unknown reason the ψ' does not decay into this particular choice of mesons pairs. The largest J/ψ mode which is missing is the $\rho\pi$ decay

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Table 1. Comparison of ψ′ and J/ψ decays

Mode	B(J/ψ→mode)	Ratio(ψ′ ÷ J/ψ in %)
$p\bar{p}$	0.22 %	8.6 ± 2.4 %
$p\bar{p}\pi^+\pi^-$	0.60	15.1 ± 4.1
$K^+K^-\pi^+\pi^-$	0.72	22.2 ± 9.0
$p\bar{p}\pi^\circ$	0.11	14.0 ± 6.3
5π	3.4	9.5 ± 2.7
7π	2.9	13.0 ± 7.0
γf(1270)	0.14	9.0 ± 3.0
ρπ	1.28	<0.63
K^*K	0.75	<2.07
γη	0.86	<1.8
γη′	0.42	<2.6

and it appears to be suppressed by a factor 20. These results indicate we may not understand the simplest picture of how gluons form into hadrons. In this paper we present a search for this decay in a new sample of ψ′ decays from the Mark III.

ψ′ Data Sample

The analysis of the mode is based on a sample of $(236\pm35)\times10^3$ ψ′ events taken with the Mark III detector at SPEAR. Approximately 40% of this data was taken in a five day run in 1982 and the remaining in a three month run in 1988. This corresponds to a total integrated luminosity of ≈0.5 inverse picobarns. The number of events were determined from a study of J/ψ production in ψ′ decays in the topologies $\psi' \to \pi^+\pi^- + J/\psi$ where the J/ψ is observed from its direct decay into $\mu^+\mu^-$ and where it's production is inferred in the recoil from the $\pi^+\pi^-$ system. The Mark III experiment[3] is a solenoidal magnetic spectrometer optimized for SPEAR physics. This analysis utilized the tracking from the drift chamber[4] and the shower information from the barrel and endcap shower counters[5]. In addition, the 1988 data had the new Mark III vertex chamber[6] in operation which achieved an average position resolution of 60 microns on Bhabha events.

$\psi' \to \rho\pi$ Analysis

The decay $\psi' \to \rho\pi$ has the final state topology of two photons and two charged pions. The charged track selection requires:

1) two and only two oppositely charged tracks that each have two DC stereo hits.
2) shower counter energy < 0.5 GeV if the track entered the shower counter.
3) mass($\pi+\pi-$)< 2.9 GeV/c^2 to remove $\psi' \to J/\psi + \pi^\circ\pi^\circ$ events.

At least two photon candidates were required in the shower counters. The two charged tracks and the two photon candidates were subjected to a kinematic constrained fit (4-C) to the decay hypothesis $\psi' \to \gamma\gamma\pi^+\pi^-$. In order to reduce the feed down from a single photon and hadronic split off's, an angle cut is imposed to remove asymmetric decays by requiring, $\cos\theta(\pi^\circ,\gamma)<0.98$, where the angle in the π° frame is between the photon and the J/ψ. A conspicuous π° signal in the $\gamma\gamma$ mass was observed as shown in Fig. 1 providing evidence for the decay $\psi' \to \pi^+\pi^-\pi^\circ$. A hand scan is performed to remove events with extra photons. Twenty $\pi^+\pi^-\pi^\circ$ candidates remain and of these events, two fall within the $\rho\pi$ bands (770±150 MeV/c^2). The first candidate had a mass, $m(\pi^-\pi^\circ)$=894 MeV/c^2 and the second had a mass, $m(\pi^+\pi^\circ)$=675 MeV/c^2. In Fig. 2 is the final Dalitz plot of the $\psi' \to \pi^+\pi^-\pi^\circ$ events. There is no evidence for the triangular $\rho\pi$ bands in the Dalitz plot.

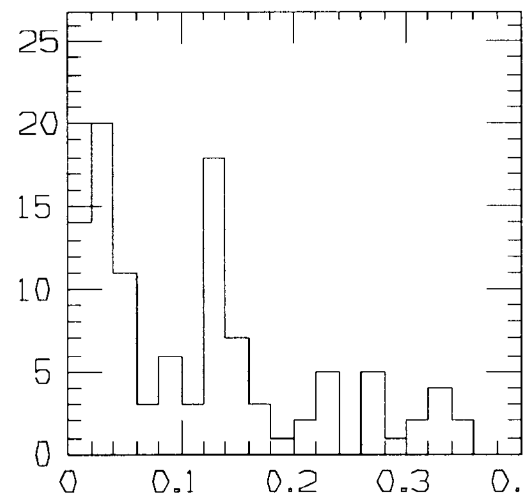

Fig. 1 $\gamma\gamma$ mass (GeV) from $\psi' \to \gamma\gamma\pi^+\pi^-$

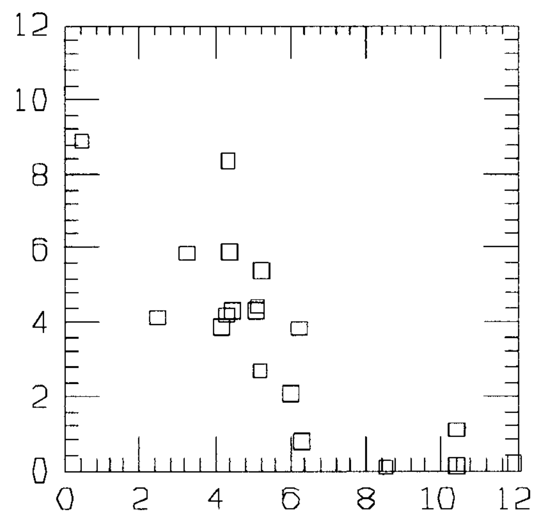

Fig. 2 Dalitz plot of $m^2(\pi^+\pi^\circ)$ vs $m^2(\pi^-\pi^\circ)$ from $\psi' \to \pi^+\pi^-\pi^\circ$

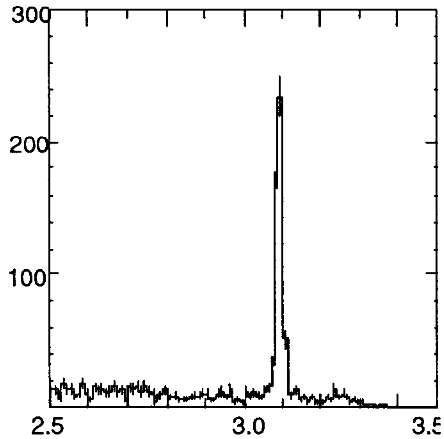

Fig.3 $\pi^+\pi^-\pi^\circ$ mass (GeV) from $\psi' \to \pi^+\pi^-\pi^+\pi^-\pi^\circ$

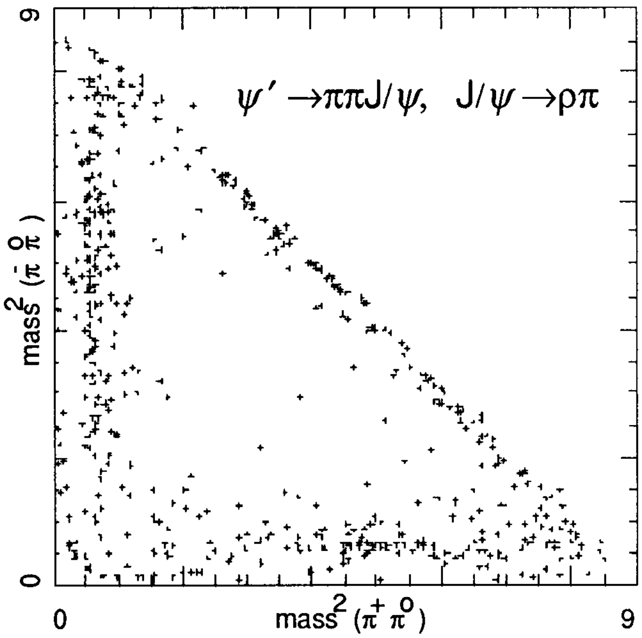

Fig. 4 Three pion Dalitz Plot of the $J/\psi \to \pi^+\pi^-\pi^\circ$ produced from the mode $\psi' \to \pi^+\pi^- J/\psi$

Several checks were performed. The same analysis program was used to analyze $J/\psi \to \pi^+\pi^-\pi^\circ$ in the J/ψ data except the e^+e^- center mass energy was changed to that of the J/ψ. A clear signal for $J/\psi \to \rho\pi$ was observed verifying that the program was correct. A second analysis was performed to detect the decay, $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \rho\pi$, $\rho\pi \to \pi^+\pi^-\pi^\circ$. In Fig. 3 is shown the $\pi^+\pi^-\pi^\circ$ mass and in Fig. 4 is the Dalitz plot of the three pions. An unmistakable J/ψ signal is evident and the Dalitz plot displays the three bands for the $\rho\pi$ decays. Hence, a $\rho\pi$ signal is definitely being produced in the ψ' data but not directly from the ψ'.

The events we observe are consistent with non-resonant 3 pion decays. If the two events we observe in the $\rho\pi$ bands are both from direct decay (this ignores the non-resonant background), we obtain;

$$B(\psi' \to \rho\pi) = \frac{2}{(.32)(236 \times 10^3)} = (2.6 \pm 1.7 \pm .5) \times 10^{-5}$$

where the Monte Carlo determined efficiency was ε=.32. If we set an upper limit at 90% C.L. for these two events, we obtain;

$$B(\psi' \to \rho\pi) < \frac{5.32}{(.32)(236 \times 10^{3})} = 7.0 \times 10^{-5}$$

Assuming all the 3 pion events are non-resonant, we obtain the branching ratio of;

$$B(\psi' \to \pi^{+}\pi^{-}\pi^{\circ}) = (2.6 \pm 0.5 \pm 0.5) \times 10^{-4}$$

These results are comparable to the Mark II results[1] which were based on 1 million ψ' decays. They had one $\rho\pi$ candidate and set an upper limit of $B(\psi'\to\rho\pi)<8.3\text{x}10^{-5}$ at 90% C.L. and from four $\pi^{+}\pi^{-}\pi^{\circ}$ events they had measured a non-resonant signal of $B(\psi'\to\pi^{+}\pi^{-}\pi^{\circ})$ $=(8.5\pm4.6)\text{x}10^{-5}$.

Discussion of the Results

Our results confirm the Mark II measurements. The observed suppression of $\psi'\to\rho\pi$ may be due to the wave function differences between the J/ψ and the ψ' but this may not explain why in particular the vector-pseudoscalar combination is missing. The interference between the OZI and the electromagnetic decays could possibly create this suppression, however, the electromagnetic contribution is too small relative to the OZI rate to suppress selectively the vector pseudoscalar rate. It is not understood whether the ψ' decay is unexpectedly suppressed or the J/ψ decay is *enhanced.* Several models have been proposed;

• *Nambu* & *Freund* Model (1975)[7]

In this model the puzzle is not the suppression of the $\rho\pi$ rate in the ψ' decays, but the existence of the $\rho\pi$ rate from the J/ψ. The rate from the J/ψ should in fact be suppressed, but it is being produced by a constructive interference from a nearby resonance. This resonance is a Pomeron daughter called the "ϑ" meson which is an SU(4) singlet vector meson that can mix with the ω, ϕ and J/ψ. It is expected to decay into $\rho\pi$ and KK^* and very little into e^+e^- or $K\overline{K}$. The model also predicts the "ϑ" mass around 1.4-1.8 GeV with a width of 50-100 MeV.

• *Hou* & *Soni* Model (1982)[8]

As in the previous model, a vector gluonia, "ϑ" interferes with the J/ψ enabling vector-pseudoscalar decays. The mass of this resonance is predicted to lie around 2.4 GeV if the ratio of the $\rho\pi$ branching ratios is 1.25% instead of the 12%. The resonance mass will also increase higher if the suppression is larger. The resonance is expected to appear in the reactions J/ψ, $\psi' \to (\eta, \eta', \pi\pi) + \vartheta$, $\vartheta \to \rho\pi, K^*K$.

• *Brodsky, Lepage* & *Tuan* Model (1987)[9]

In this model, a vector gluonium resonance is proposed to lie within 100 MeV of the J/ψ and the interference produces the vector pseudoscalar decays of the J/ψ. This explains the puzzle as to why QCD hadron helicity conservation[10] fails to suppress the large $\rho\pi$ decay of the J/ψ. In addition this may explain why $J/\psi \to \phi S^*$ and not $\delta\pi$ is observed, since the ϑ mixes with the ϕ and enhances a mode that would otherwise be suppressed.

• *Slaugher* & *Oneda* Model (1988) [11]

In this model the vector glueball that mixes with the J/ψ is proposed also to explain why the decay $J/\psi \to \gamma\eta_c$ is so small (1.3%). In the charmonium model the M1 transition of J/ψ is expected to be a factor of three larger than observed.

• *Tornquist* & *Chaichian* Model (1988)[12]

In this model the puzzle is explained by introducing a hadronic form factor that exponentially decreases the two meson decays of the ψ' relative to the J/ψ by $\exp[-(m(\psi')^2 - m(J/\psi)^2/4K^2]$ where K is a parameter fitted to the data. This prediction explains the decay rate for $\phi \to \rho\pi$ and predicts a large suppression for many two meson modes.

• *Pinsky* Model (1989)[13]

In this paper it is pointed out that the radiative decay of the η from the ψ' is a hindered M1 transition. The radiative transitions to the η are predicted to scale as the η_c rates corrected for the phase space factors as;

$$\frac{B(\psi' \to \gamma\eta)}{B(J/\psi \to \gamma\eta)} = \left(\frac{p_\eta^{\psi'}}{p_\eta^{J/\psi}}\right)^3 \left(\frac{p_{\eta_c}^{J/\psi}}{p_{\eta_c}^{\psi'}}\right)^3 \frac{B(\psi' \to \gamma\eta_c)}{B(J/\psi \to \gamma\eta_c)} = 0.2\%$$

This predicts a small rate for the radiative η decay from the ψ′. Using a phenomenological model where the J/ψ has an OZI amplitude, F_V,to change into a light quark vector meson which subsequently decays into a vector pseudoscalar pair with a coupling, $G_{V \to vp}$, the ψ′ is then expected to have an OZI amplitude, $F_{V'}$, to change into a radial light quark vector meson which subsequently decays into a vector pseudoscalar pair with a coupling, $G_{V' \to vp}$. This coupling, $G_{V' \to vp}$ for a radial vector meson to change into a vector pseudoscalar pair is then determined from measured transition rates for $\psi' \to \gamma\eta_c$ and found to be suppressed relative to $G_{V \to vp}$ which is evidence for a generalized hindered M1 transition. Using estimates for the OZI amplitudes, the final predicted rate for $\psi' \to \rho\pi$ is slightly less than 10^{-5}.

Summary

In conclusion, we have set an upper limit, $B(\psi' \to \rho\pi) < 7.0 \times 10^{-5}$ at 90% C.L. We observe, however, non-resonant three pion decays in the same data sample. This result confirms the previous search from Mark II.[1] These results are still theoreitcally puzzling and indicate the existence of more underlying complexity in the physics of hadronic decays of the J/ψ and ψ′. We thank the efforts of the SPEAR staff for the operation of the storage ring and the SLAC Technical staff for the operation of the LINAC that enabled the data runs for the ψ′

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