SLAC PUB 5114
UWSEA PUB 89-20
October 1989
(E/T)

Recent ψ' Results from Mark III*

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Abstract

Results on ψ' decays from Mark III are presented. With a data sample of 240,000 ψ' events, we measure $\psi'\to\pi^+\pi^-\psi$, $\psi'\to\eta\psi$, $\psi'\to\gamma\chi_c$, $\psi'\to\gamma 4\pi^\pm$, $\psi'\to\gamma 6\pi^\pm$, and perform a search for $\psi'\to\rho\pi$. Implications of our measurements are discussed.

1. Introduction

Fifteen years after its discovery, the charmonium system (Fig. 1) still poses many unanswered experimental and theoretical questions.

The ψ' [1] is the 2^3S_1 $c\bar{c}$ vector meson. It is the only well established radial excitation of the ψ. There are many measurements to be made at the ψ'. Two of the low-lying charmonium states are still unconfirmed, although there is evidence for both. Indications for the $^1P_1$ state, h_c, were reported by the ISR experiment R704[2], but have not been seen at e^+e^- machines. It is important to verify the η_c', which has only been observed as the recoil mass of a photon coming from ψ' decays[3], and measure its exclusive decays. Little is known about hadronic and radiative decays of

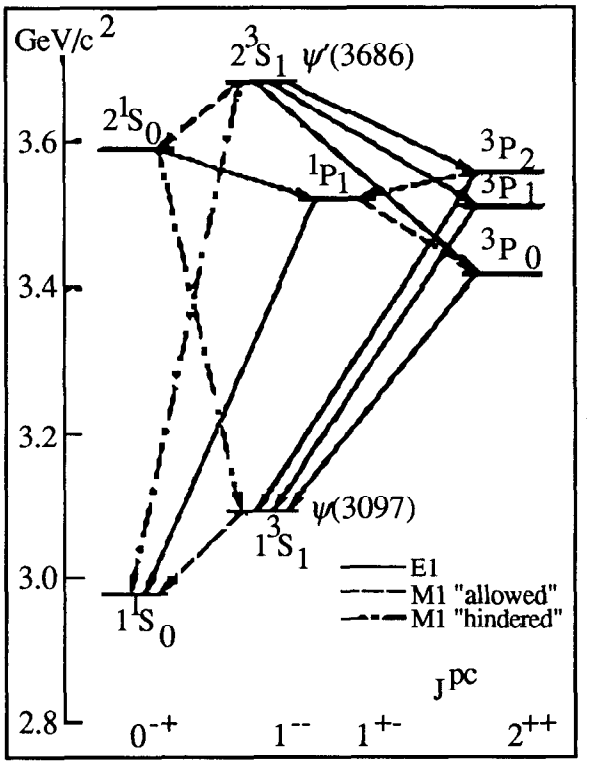

FIG 1: The charmonium system.

* Work supported by the Department of Energy contract DE-AC03-76SF00515 and by the National Science Foundation.

Presented at the Europhysics Conference on High-Energy Physics, Madrid, Spain, Sept. 6-13, 1989
and at the 3rd Int. Conference on Hadron Spectroscopy, Ajaccio, France, Sept. 23-27, 1989.

the χ_c and η_c states.

From $\psi' \to \pi^+\pi^-\psi$ decays one can study the all neutral ψ decays, and also normalize the current Mark III ψ data. In addition, an accurate measurement of $\psi \to \mu^+\mu^-$ will reduce the error on α_s through the relation[4]:

$$\frac{\Gamma(\psi \to ggg)}{\Gamma(\psi \to \mu^+\mu^-)} = \frac{5}{18}\frac{M^2}{4m_c^2}\frac{(\pi^2-9)(\alpha_{s(m_c)})^3}{\pi\alpha^2}(1+\frac{1.6\alpha_s}{\pi}).$$

The error on $\psi \to \mu^+\mu^-$ is currently 13%. One can also search for vector glueball candidates, which might be near the ψ. Their possible mixing with the ψ will be discussed below.

Several experiments have previously studied the ψ'. Most results come from Mark I with $0.4\text{x}10^6$ ψ' events, Mark II with $1.0\text{x}10^6$ ψ' events, and Crystal Ball with $1.8\text{x}10^6$ ψ' events. These events were all collected at the SPEAR e^+e^- storage ring at SLAC.

Mark III at SPEAR has recently completed a data taking run at the ψ' energy. Our results are based on a sample of $(236\pm35)\text{x}10^3$ ψ' events. Approximately 40% of this data was taken in a five day run in 1982, and the remainder in a three month run in the fall of 1988. In this paper we present results on $\psi' \to \pi^+\pi^-\psi$, $\psi' \to \eta\psi$, $\psi' \to \gamma\chi_c$, $\psi' \to \gamma 4\pi^\pm$, $\psi' \to \gamma 6\pi^\pm$, and perform a search for $\psi' \to \rho\pi$.

2. Inclusive $\psi' \to \pi^+\pi^-\psi$ decays.

The $\psi' \to \pi^+\pi^-\psi$ decay is used to determine the number of ψ' events in two independent ways. In the first, inclusive ψ production from $\psi' \to \pi^+\pi^-\psi$ is measured. Events were selected with at least two charged tracks, assumed to be pions. The recoil mass from the $\pi^+\pi^-$ system is shown in Fig. 2a. A clear ψ peak is seen. No hints of resonance structure other than the ψ are seen. To estimate the number of ψ' events, the PDG[5] value for $\psi' \to \pi^+\pi^-\psi$ was used.

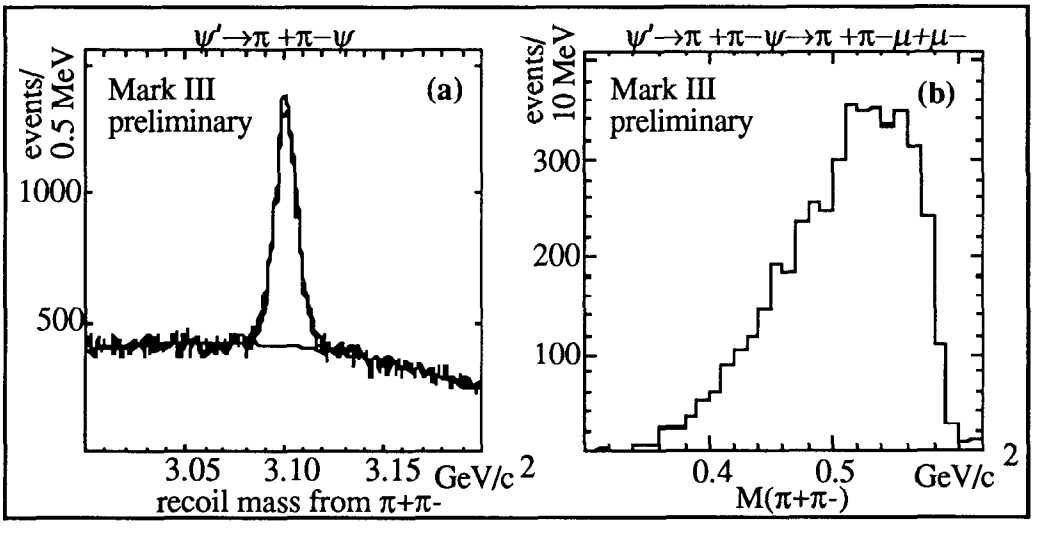

FIG 2: $\psi' \to \pi^+\pi^-\psi$. a) recoil mass from $\pi^+\pi^-$; b) $M(\pi^+\pi^-)$.

The $\overline{M}_{\pi^+\pi^-}$ is shown in Fig. 2b. The shape of the $\pi^+\pi^-$ spectrum peaks at high masses, as observed in previous experiments. No hints of resonance structure is seen. A theoretical discussion of this shape can be found in [6].

In the second method, $\psi' \rightarrow$neutrals+ψ, $\psi \rightarrow \mu^+\mu^-$ was detected and PDG values for $\psi' \rightarrow$neutrals+ψ and $\psi \rightarrow \mu^+\mu^-$ were used to measure the number of ψ' events. The two methods agree to within 1%. The weighted average of events found is: $(236\pm35)\times10^3$.

3. $\psi' \rightarrow \gamma\gamma\psi \rightarrow \gamma\gamma e^+e^-(\mu^+\mu^-)$ decays.

Events were selected with two charged tracks and two or more photons. The events were fit to $\psi' \rightarrow \gamma\gamma e^+e^-$ or $\psi' \rightarrow \gamma\gamma \mu^+\mu^-$, with the mass of the two charged tracks constrained to the ψ mass. The fit with the best probability was kept. Fig. 3a shows a scatter plot of $M(\gamma\gamma)^2$ vs. $M_{high}(\gamma\psi)^2$, where $M_{high}(\gamma\psi)$ is the high mass $\gamma\psi$ combination. Fig. 3b shows the $M(\gamma\gamma)$ distribution. A clear η signal is seen. The Monte Carlo efficiency is 56%, and the mass resolution 3 MeV. We measure a preliminary branching ratio of:

$$B(\psi' \rightarrow \eta\psi) = (2.5\pm0.2\pm0.7)\%.$$

Fig. 3c shows the $M_{high}(\gamma\psi)$ distribution after cutting away the area $0.540<M(\gamma\gamma)<0.556$ GeV/c^2 (the η region). We observe the χ_{c1} and χ_{c2} states. The Monte Carlo efficiency is 54%, and the mass resolution 7 MeV. We measure preliminary branching ratios of:

$$B(\psi' \rightarrow \gamma\chi_{c1}) = (9.4\pm0.5\pm2.5)\% \quad \text{and} \quad B(\psi' \rightarrow \gamma\chi_{c2}) = (11.0\pm0.7\pm2.9)\%,$$

where the first error is statistic and the second systematic.

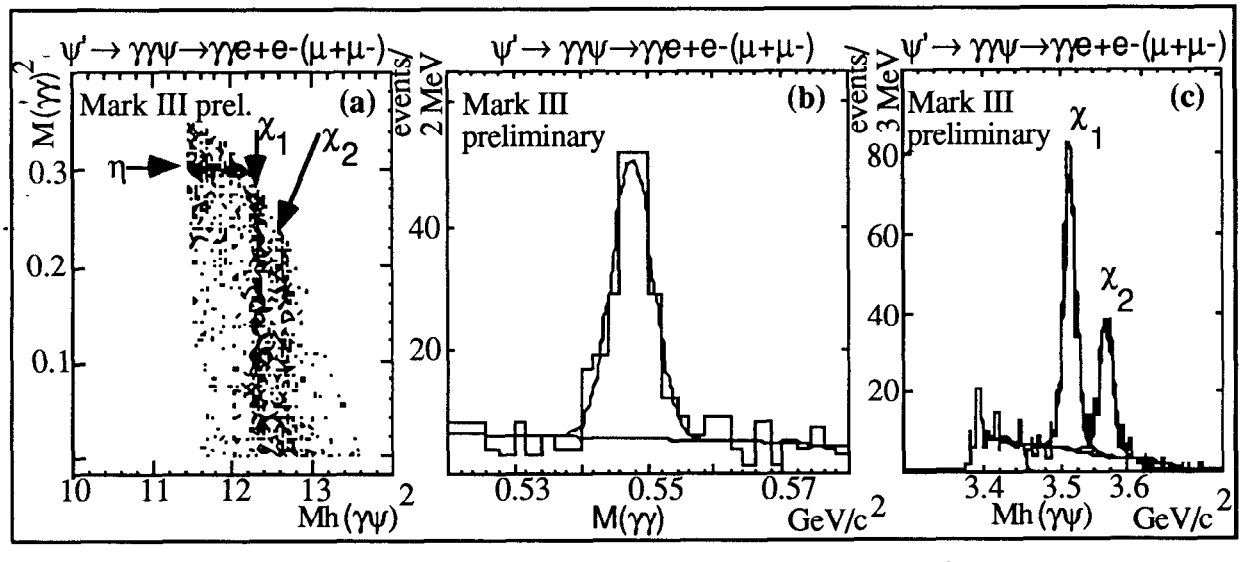

FIG 3: $\psi' \rightarrow \gamma\gamma\psi \rightarrow \gamma\gamma e+e-(\mu+\mu-)$. a) scatter plot of $M(\gamma\gamma)^2$ vs. $M_{high}(\gamma\psi)^2$; b) $M(\gamma\gamma)$; c) $M_{high}(\gamma\psi)^2$ after an anti η cut.

4. $\psi' \to \gamma 4\pi^{\pm}$, $\psi' \to \gamma 6\pi^{\pm}$.

To study the $\gamma 4\pi^{\pm}$ final state, events were selected with four charged tracks and one or more photons. The events were fit to $\psi' \to \gamma 4\pi^{\pm}$. The fit with the best probability was kept. Events were rejected if the recoil mass from any $\pi^+\pi^-$ pair was equal to M_ψ. The mass of the $4\pi^{\pm}$ system is shown in Fig. 4a. The χ_c states are clearly seen. The Monte Carlo efficiency is 23%, and the mass resolution 13 MeV.

For the $\gamma 6\pi^{\pm}$ final state, events were selected with six charged tracks and one or more photons. The events were fit to $\psi' \to \gamma 6\pi^{\pm}$. The fit with the best probability was kept. Events were rejected if the recoil mass from any $\pi^+\pi^-$ pair was equal to M_ψ. The mass of the $6\pi^{\pm}$ system is shown in Fig. 4b. Again, clear χ_c states are seen, though the χ_{c1} and χ_{c2} are not as well resolved. The Monte Carlo efficiency is 24%, and the mass resolution 17 MeV.

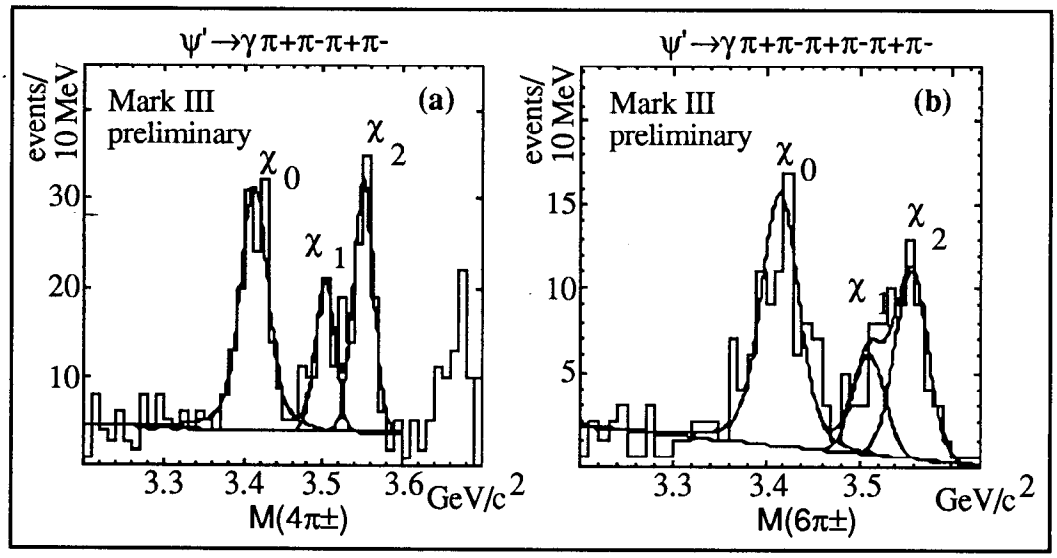

FIG 4: a) $\psi' \to \gamma 4\ \pi^{\pm}$; b) $\psi' \to \gamma 6\ \pi^{\pm}$.

We measure preliminary branching ratios of:

$B(\psi' \to \gamma\chi_c)(\chi_c \to 4\pi^{\pm})$:	$B(\psi' \to \gamma\chi_c)(\chi_c \to 6\pi^{\pm})$:
$\chi_{c0}=(2.4\pm0.2\pm0.7)\times10^{-3}$	$\chi_{c0}=(1.46\pm0.15\pm0.43)\times10^{-3}$
$\chi_{c1}=(0.93\pm0.13\pm0.28)\times10^{-3}$	$\chi_{c1}=(0.44\pm0.10\pm0.15)\times10^{-3}$
$\chi_{c2}=(1.9\pm0.2\pm0.6)\times10^{-3}$	$\chi_{c2}=(0.88\pm0.20\pm0.27)\times10^{-3}$.

5. The ρπ puzzle.

The hadronic decay rate of the ψ' relative to the ψ should scale as the ratio of the three gluon widths, which are proportional to the leptonic widths divided by the full widths:

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

Previous experiments (Mark I, Mark II and Crystal Ball) have measured several hadronic decay modes of the ψ′ that scale to 13% of the ψ rate, but did not observe any of the vector-pseudoscalar (VP) combinations! In particular, the ρπ decay of the ψ has a large branching ratio (1.3%), while the ρπ decay of the ψ′ is not seen (<0.008% at 90% C.L.[7]). The comparison between observed and predicted ψ′ decay rates is shown in Fig. 5, where *R*, the ratio of the measured $B(\psi'\to X)$ divided by the expected $0.13\cdot B(\psi\to X)$, is shown for various hadronic final states.

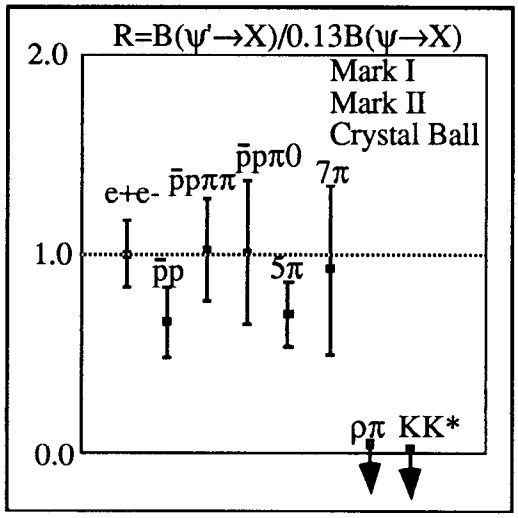

FIG 5: $R=B(\psi'\to X)/0.13B(\psi\to X)$.

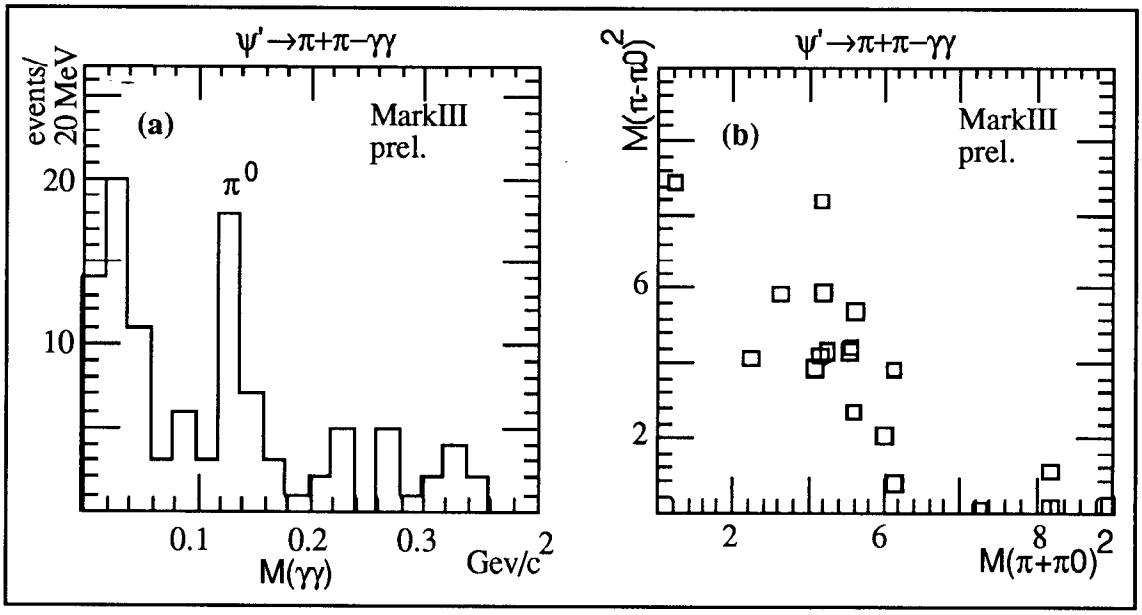

FIG 6: $\psi'\to\gamma\gamma\pi^+\pi^-$; a) $M(\gamma\gamma)$; b) $M(\pi^+\pi^\circ)^2$ vs. $M(\pi^-\pi^\circ)^2$.

The Mark III data is used to search for $\psi'\to\rho\pi$. Events were selected with two charged tracks and two or more photons. The events were fit to $\psi'\to\gamma\gamma\pi^+\pi^-$. The fit with the best probability was kept. Events were rejected if the recoil mass from the $\pi^+\pi^-$ pair was consistent with M_ψ. The γγ mass is shown in Fig. 6a. A small π° signal is seen, providing evidence for $\psi'\to\pi^+\pi^-\pi^\circ$. A handscan is performed to remove events with extra photons. The dalitz plot of the $\pi^+\pi^-\pi^\circ$

events is shown in Fig. 6b. Twenty $\pi^+\pi^-\pi^\circ$ events remain, two of which fall in the $\rho\pi$ bands (770±150 MeV/c^2).There is no evidence for the triangular $\rho\pi$ bands observed in $\psi\to\rho\pi$[8]. We therefore set an upper limit for these two events. The Monte Carlo efficiency is 32%. We obtain:

$$B(\psi'\to\rho\pi) < 7.0 \times 10^{-5} \text{ (90\% C.L.).}$$

Assuming all three pion events are non-resonant, we obtain:

$$B(\psi'\to\pi^+\pi^-\pi^\circ) = (0.26\pm0.05\pm0.05)\times10^{-3}.$$

Our results confirm the Mark II measurement. It is not understood whether the ψ' decay is unexpectedly suppressed or the ψ decay enhanced. Because of the well defined nature of this puzzle, there have been a number of theoretical attempts to explain it.

Freund and Nambu[9], and later Hou and Soni[10] suggested that a vector glueball near the ψ couples strongly to VP pairs, but not to e^+e^-, thus enhancing the rate at the ψ. Brodsky, Lepage and Tuan[11] refined this notion with the observation that VP final states are suppressed by the QCD theorem for ψ decays, but not for the decays of the glueball. Another model is that of Chaichian and Tornqvist[12] who propose that the effect is due to form factors. A recent model by Pinsky[13], relates the VP decays of the ψ' and ψ to their decays into $\gamma\eta_C$, and observes that $\psi'\to\gamma\eta_C$ is a hindered M1 transition.

6. Conclusions.

Our results are summarized and compared to other experiments in Table I. Many of the Mark II[14] results are not included in the PDG average, and are therefore shown in a separate column.

TABLE I. ψ' branching ratios.

Reaction	**Mark III**	**PDG** average	**Mark II**(thesis)
$\psi'\to\eta\psi$	(2.5±0.2±0.7)%	(2.7±0.4)%	
$\psi'\to\gamma\chi_{c1}$	(9.4±0.5±2.5)%	(8.7±0.8)%	
$\psi'\to\gamma\chi_{c2}$	(11.0±0.7±2.9)%	(7.8±0.8)%	
$\psi'\to\gamma\chi_{c0}\to\gamma4^\pm$	$(2.4\pm0.12\pm0.7)\times10^{-3}$	$(3.4\pm0.6)\times10^{-3}$	$(2.1\pm0.2)\times10^{-3}$
$\psi'\to\gamma\chi_{c1}\to\gamma4^\pm$	$(0.93\pm0.13\pm0.28)\times10^{-3}$	$(1.4\pm0.4)\times10^{-3}$	$(0.8\pm0.1)\times10^{-3}$
$\psi'\to\gamma\chi_{c2}\to\gamma4^\pm$	$(1.9\pm0.2\pm0.6)\times10^{-3}$	$(1.7\pm0.4)\times10^{-3}$	$(1.3\pm0.1)\times10^{-3}$
$\psi'\to\gamma\chi_{c0}\to\gamma6^\pm$	$(1.46\pm0.15\pm0.43)\times10^{-3}$	$(1.4\pm0.5)\times10^{-3}$	$(1.8\pm0.3)\times10^{-3}$
$\psi'\to\gamma\chi_{c1}\to\gamma6^\pm$	$(0.44\pm0.10\pm0.15)\times10^{-3}$	$(1.9\pm0.7)\times10^{-3}$	$(0.9\pm0.2)\times10^{-3}$
$\psi'\to\gamma\chi_{c2}\to\gamma6^\pm$	$(0.88\pm0.20\pm0.27)\times10^{-3}$	$(0.94\pm0.62)\times10^{-3}$	$(1.7\pm0.3)\times10^{-3}$
$\psi'\to\rho\pi$	$<7\times10^{-5}$ (90% cl)	$<8.3\times10^{-5}$(90%cl)	

In summary, Mark III has obtained a rather small ψ' data sample. With this data, precise measurements of ψ' branching ratios have been obtained. The $\rho\pi$ puzzle persists. New theoretical models try to explain the discrepancy between ψ' and ψ decays to VP mesons. More data is clearly needed to unveil the other experimental questions that remain unsolved.

I wish to thank the SPEAR and SLAC Technical staff. I sincerely thank Gary Gladding who presented these results on my behalf at Madrid.

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