J/ψ AND ψ' DECAYS INTO TWO HADRONS

W. BRAUNSCHWEIG, H.-U. MARTYN, H.G. SANDER, D. SCHMITZ, W. STURM, W. WALLRAFF
I. Physikalisches Institut der RWTH Aachen, Germany

K. BERKELMAN[1], D. CORDS, R. FELST, E. GADERMANN, B. GITTELMAN[2], H. HULTSCHIG, P. JOOS, W. KOCH, U. KÖTZ, H. KREHBIEL, D. KREINICK, W.A. McNEELY, K.C. MOFFEIT, A. PETERSEN, B.H. WIIK and G. WOLF
Deutsches Elektronen-Synchrotron DESY, Germany

G. GRINDHAMMER, J. LUDWIG, K.H. MESS, G. POELZ, J. RINGEL, K. SAUERBERG and P. SCHMÜSER
II. Institut für Experimentalphysik der Universität Hamburg, Germany

W. De BOER, G. BUSCHHORN, B. GUNDERSON, R. KOTTHAUS, U.E. KRUSE[3], H. LIERL, H. OBERLACK, K. PRETZL and M. SCHLIWA
Max-Planck-Institut für Physik und Astrophysik, München, Germany

S. ORITO, T. SUDA, Y. TOTSUKA and S. YAMADA
University of Tokyo, Tokyo, Japan

Received 14 June 1976

Branching ratios have been determined for the decays of J/ψ and ψ' into $\pi^+\pi^-$, K^+K^-, $p\bar{p}$, $\pi^\pm\rho^\mp$ and $K^\pm K^*(892)^\mp$. Results on a search for other two body decays of J/ψ and ψ' are given. Also presented are values for the π and K form factors at $\sqrt{s} = 3.1$ and 3.7 GeV.

The hadronic two body decay rates of J/ψ and ψ' provide a measure of the SU_3 properties of these resonances. Moreover, at these resonances the one-photon decay channels are enhanced, which makes it possible to measure the form factors for those final states reached only by one-photon decay.

We have used the double-arm spectrometer DASP and the DESY storage rings DORIS to study the decays of J/ψ and ψ' into two charged hadrons. First results on the decays $J/\psi \to \pi^+\pi^-$, K^+K^- and $\bar{p}p$ with a fifth of the present statistics have already been reported [1]. A detailed description of DASP was given in refs. [1] and [2]. It consists of two identical magnetic spectrometers symmetrically positioned with respect to the interaction point. Together the arms cover a geometrical solid angle of 0.9 sr. A non magnetic detector subtending 70% of 4π is located between the magnets. The spectrometer arms provide high momentum resolution ($\Delta p/p = \pm 0.007 \cdot p$ (GeV/c, rms), good particle identification by means of range and shower counters, and a precise time-of-flight measurement ($\Delta\tau = \pm 0.26$ ns rms over a flight path of 5 m).

Different trigger conditions and analyses were employed for those two body final states where neither particle decays strongly (e.g. $\pi^+\pi^-$) and those with only one stable particle (e.g. $\pi^+\rho^-$). We therefore discuss the two cases separately.

$\pi^+\pi^-$, K^+K^- and $p\bar{p}$ pairs. The two final state particles were detected in opposite spectrometer arms. The event selection criteria were basically the same as in ref. [1]. They involved

– a momentum cut on both tracks (corresponding to $\pm 2\sigma$ for $\pi^+\pi^-$ and K^+K^- candidates and $\pm 3\sigma$ for $p\bar{p}$ candidates);

– a collinearity cut (0.1 rad in the projected angles);

– a vertex cut;

[1] Now at Cornell University, Ithaca, N.Y., USA.
[2] On leave from Cornell University, Ithaca, N.Y., USA.
[3] Now at University of Illinois, Urbana, Ill., USA.

Table 1
Branching ratios for J/ψ and ψ' decays. The upper limits are given for a confidence level of 90%.

	J/ψ			ψ'		
Decay mode	Number of events	$\Gamma_f/\Gamma_{\mu\mu}$	Γ_f/Γ_{tot}	Number of events	$\Gamma_f/\Gamma_{J/\psi X}$	Γ_f/Γ_{tot}
$\pi^+\pi^-$	2	$(1.4\pm1.0)\times10^{-3}$	$(1\ \pm0.7)\times10^{-4}$	0	$<6.5\times10^{-4}$	$<3.7\times10^{-4}$
K^+K^-	1	$(2\pm2)\times10^{-3}$	$(1.4\pm1.4)\times10^{-4}$	2	$<2.5\times10^{-3}$	$<1.4\times10^{-3}$
$p\bar{p}$	70	$(3.3\pm0.4)\times10^{-2}$	$(2.3\pm0.3)\times10^{-3}$	0	8.2×10^{-3}	$<4.7\times10^{-4}$
$\pi^\pm\rho^\mp$	99±25	0.11±0.03	$(7.8\pm1.9)\times10^{-3}$			
$\pi\rho$ [a]			$(1.2\pm0.3)\times10^{-2}$			
$KK^*(892)^\mp$	39±10	0.059±0.017	$(4.1\pm1.2)\times10^{-3}$			
$KK^*(892)$ [a]			$(8.2\pm2.4)\times10^{-3}$			
$\pi^\pm A_2$		<0.06	$<4.3\times10^{-3}$			
$KK^*(1420)^\mp$		<0.05	$<3.3\times10^{-3}$			
$\pi^\pm R(3100)^\mp$						<0.04

[a] By isospin invariance.

– for $\pi^+\pi^-$ and K^+K^- a cut on the energy deposited in the shower counters (less than three times that for a minimum ionizing particle);

– rejection of events which had a range counter fired (= muon candidate);

– a cut in the particle velocity β (deviation from the nominal value less than 2σ in the case of $\pi^+\pi^-$ and K^+K^-, and less than $\sim 4\sigma$ for $p\bar{p}$);

– a cut in the polar angle for $\pi^+\pi^-$ and K^+K^- candidates (depending on charge and magnet polarity: $-0.25<\cos\theta<0.55$ or $-0.55<\cos\theta<0.25$).

Table 1 summarizes the results on $\pi^+\pi^-$, K^+K^- and $p\bar{p}$ pairs obtained for total luminosities of 390 nb^{-1} and 370 nb^{-1} spent at the J/ψ and ψ' resonances. Two $\pi^+\pi^-$ and one K^+K^- candidate were observed at the J/ψ. The background expected from μ pair and Bhabha pair production is 0.24 and 0.2 events respectively. Fig. 1a shows the invariant mass distribution for collinear pp pairs observed at the J/ψ. It shows a clear signal for the $J/\psi \to p\bar{p}$ decay. At the ψ' no $\pi^+\pi^-$, two K^+K^- and no $p\bar{p}$ candidates were found.

In order to determine branching ratios we used for the J/ψ the events from μ pair production, $J/\psi \to \mu^+\mu^-$, and for the ψ' the cascade events $\Psi' \to XJ/\psi$, $J/\psi \to \mu^+\mu^-$ observed in the same experiments. Cuts equivalent to those used in selecting the two body hadronic candidates were applied. In the case of the J/ψ the QED contribution to μ pair production was subtracted. The polar angle distribution for the $\pi^+\pi^-$ and K^+K^- decays has to be of the form $W(\cos\theta) \sim \sin^2\theta$ and this angular dependence was used to integrate the decay distribution over the full solid angle ‡. For $p\bar{p}$ decay the general form of the decay angular distribution is

$$W(\cos\theta) \sim |G_E|^2 \sin^2\theta + \frac{s}{4m^2}|G_M|^2(1+\cos^2\theta),$$

where G_E, G_M are the electric and magnetic form factors of the nucleon, m is the nucleon mass and s is the total energy squared. Fig. 1b shows the polar angle distribution for $p\bar{p}$ events from J/ψ decay. The curves show the $\cos\theta$ dependence expected if G_E or G_M vanishes. The case $G_E = 0$ is slightly favored by the data. An angular dependence $W(\cos\theta) \sim 1+\cos^2\theta$ was assumed to integrate over the full solid angle. Using the known branching ratios $\Gamma_{\mu\mu}/\Gamma_{tot}$ and $\Gamma_{\psi'\to J/\psi X}/\Gamma_{tot}$ (ref. [3]) we arrived at the branching ratios and decay widths given in table 1. Results on $J/\psi \to p\bar{p}$ from other experiments are in agreement with our value [4, 5].

$\pi^\pm\rho^\mp$ and $K^\pm K^{*\mp}(892)$ production. The J/ψ decays into $\pi\rho$ and KK^* were studied in the missing mass spectra of the inclusive reactions $J/\psi \to \pi^\pm X$ and $J/\psi \to K^\pm X$ where the $\pi^\pm$ or $K^\pm$ was detected by one of the spectrometer arms. A detailed account of the event analysis was presented in ref. [2]. Here we stress

‡ Effects from beam polarization were negligible.

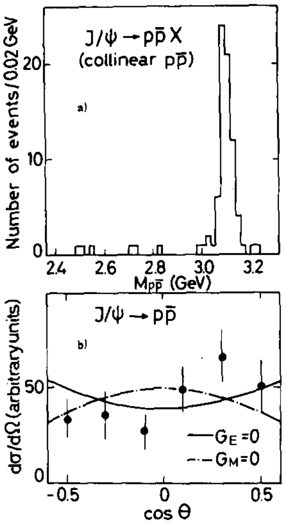

Fig. 1. (a) Effective $p\bar{p}$ mass distribution for collinear p, $\bar{p}$ pairs from $J/\psi \to p\bar{p}X$. (b) Polar angle distribution for $J/\psi \to p\bar{p}$; θ is the angle between the proton and the positron beam.

only that a purely inclusive trigger was employed to detect these reactions, so that the triggering efficiency was independent of the nature of the final state X. The total integrated luminosities in this study were 170 nb^{-1} at the J/ψ and 210 nb^{-1} at the ψ'.

Fig. 2 shows the distribution of the $\pi^{\pm}X$ and $K^{\pm}X$ events as a function of the missing mass X. Clear signals for ρ and K^* production are observed. The distributions were fit to a sum of a Breit Wigner for the ρ (or K^*), folded with a Gaussian to account for the momentum resolution ($\sigma_M \approx 70$ MeV at the ρ, $\sigma_M \approx 50$ MeV at the K^*) and a polynomial background. The curves in figs. 2a, b show the resulting fits. The angular distribution for $\pi\rho$ and KK^* production is of the form $W(\cos\theta) \sim 1 + \cos^2\theta$. This was used to integrate over the full solid angle. Corrections were applied for losses due to inefficiencies in the track reconstructions, decay in flight and nuclear absorption (see ref. [2]). The resulting branching ratios are given in table 1. Our value for the $KK^*(892)$ branching ratio is somewhat larger than the value given in ref. [5].

Other two-meson channels. The missing mass spectra (figs. 2a, b) show no evidence for the decays $J/\psi \to \pi^{\pm}A_2^{\mp}$, $K^{\pm}K^*(1420)^{\mp}$. Upper limits on the branching ratios are given in table 1.

Some colour models predicted the ψ' to decay into a narrow charged state R via $\psi' \to \pi^{\pm}R$ where R has

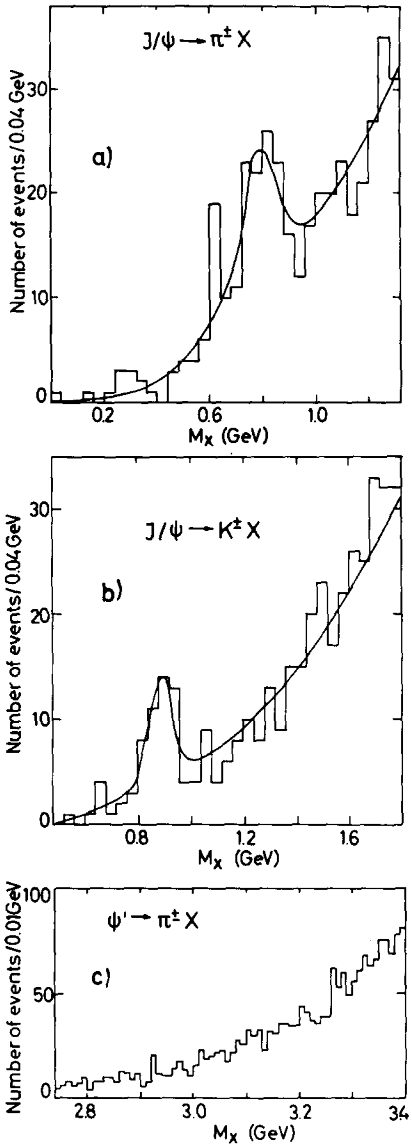

Fig. 2. Missing mass spectrum observed in the decay (a) $J/\psi \to \pi^{\pm}X$, (b) $J/\psi \to K^{\pm}X$, (c) $\psi' \to \pi^{\pm}X$. The curves are explained in the text.

a mass close to that of the J/ψ [e.g. 6]. Fig. 2c shows the missing mass spectrum in that mass spectrum in that mass range. No enhancement is observed and an upper limit of 4% can be placed for $\Gamma_{\psi' \to \pi^{\pm}R}/\Gamma_{\psi' \to all}$ assuming $\Gamma_R < 30$ MeV.

Discussion of the results. Relative to the $J/\psi \to p\bar{p}$ decay rate the $\pi^+\pi^-$ and K^+K^- decay modes are strongly suppressed. In the case of the $\pi^+\pi^-$ this is consistent with the isospin and G-parity assignment of 0^- for the J/ψ. The smallness of K^+K^- suggests that the J/ψ is an SU_3 singlet state. The same conclusion is reached from the relative size to the $\pi\rho$ and KK*(892) branching ratios. If the J/ψ has both singlet and octet components the decay amplitude will be of the form [7]

$$A(\pi^{\pm}\rho^{\mp}) = A_1 - 2A_8\,, \quad A(K^{\pm}K^{*\mp}) = A_1 + A_8\,.$$

Inserting the measured branching ratios and correcting for phase space (factor 0.85) one finds

$$|A_8|/|A_1|\cos\delta = -0.07 \pm 0.06\,,$$

where δ is the phase between A_1 and A_8. Hence the J/ψ is predominantly an SU_3 singlet state.

Assuming that the J/ψ and ψ' decay into $\pi^+\pi^-$ or K^+K^- only via the one-photon channel the π and K form factors are given by, e.g. $|F_\pi|^2 = 4\Gamma_{\pi^+\pi^-}/\Gamma_{\mu\mu}$:

$\sqrt{s} = 3.1$ GeV,

$$|F_{\pi^\pm}|^2 = (5.6 \pm 4.0) \times 10^{-3}\,, \quad |F_{K^\pm}|^2 = (8 \pm 8) \times 10^{-3}\,,$$

$$\sqrt{s} = 3.7\ \text{GeV}, \quad |F_{\pi^\pm}|^2 < 0.15\,, \quad |F_{K^\pm}|^2 < 0.6\,.$$

A simple rho pole, $F_\pi = (1 - s/m_\rho^2)^{-1}$, has the value $|F_\pi|^2 = 4.5 \times 10^{-3}$ at $\sqrt{s} = 3.1$ GeV, which is consistent with the data.

The ratio of $p\bar{p}$ to $\mu^+\mu^-$ production measured at the J/ψ is larger than any plausible extrapolation of this ratio measured below the J/ψ (see ref. [1]). The $p\bar{p}$ decay is therefore a direct decay of the J/ψ.

We thank Dr. T. Walsh for discussions. We thank all engineers and technicians of the collaborating institutions who have participated in the construction of DASP. The invaluable cooperation with the technical support groups and the computer center at DESY is gratefully acknowledged. We are indebted to the DORIS machine group for their excellent support during the experiment. The non-DESY members of the collaboration thank the DESY Direktorium for the kind hospitality extended to them.

References

[1] DASP collaboration, Phys. Letters 57B (1975) 297.
[2] DASP collaboration, DESY Report 76/21 (1975), submitted to Physics Letters.
[3] G.S. Abrams et al., Phys. Rev. Letters 34 (1975) 481.
[4] L. Criegee et al., Contribution to the 1975 Intern. Conf. on Lepton and photon interactions at high energies, Stanford, USA.
[5] SLAC-LBL collaboration, data reported by V. Lüth, rapporteur talk at the EPS Intern. Conf. on High energy physics, Palermo, Italy, 1975 and SLAC-PUB-1617, LBL-4211 (1975);
F. Vanucci et al., SLAC-PUB-1724; LBL-4699 (1976).
[6] B. Stech, talk given at the Intern. Summer Institute 1975, Hamburg, Springer Tracts, to be published.
[7] S. Rudaz, Cornell preprint CLNS-324 (1975);
T. Walsh and H. Kowalski, DESY Report 76/2 (1975), Phys. Rev., to be published.