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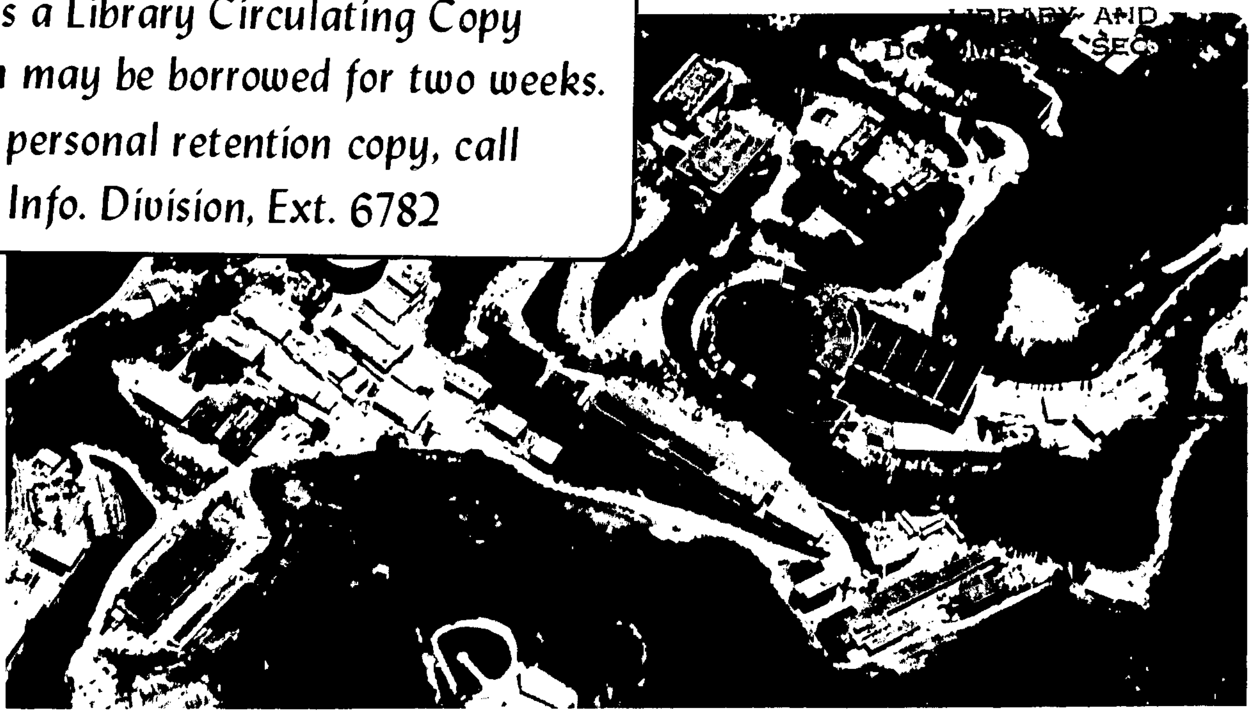

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MEASUREMENT OF THE PARAMETERS OF THE $\psi(3770)$ RESONANCE*

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ABSTRACT

We present a measurement of the cross section for hadron production by e^+e^- annihilation in the vicinity of the previously observed resonance near 3.77 GeV. The data are used to determine the parameters of the $\psi(3770)$ resonance. The values found are: mass 3764 ± 5 MeV/c^2, total width 23.5 ± 5 MeV, and partial width to electron pairs 276 ± 50 eV.

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The $\psi(3770)$ resonance observed in e^+e^- annihilation to hadrons lies just above the threshold for pair production of D mesons.[1,2] Because of the simple threshold kinematics and relatively large pair production rates for charged and neutral D mesons, the $\psi(3770)$ represents a convenient source of charmed D mesons for studies of their decay properties. Precise knowledge of the parameters of this resonance is important both for comparison with the charmonium model of the ψ family[3] as well as assisting in the determination of absolute branching ratios of D meson decay. The two previous measurements of the leptonic partial width differed significantly.[1,2]

We present here an analysis of cross section data obtained during a contiguous period of time at 23 center-of-mass energies (E_{cm}) over the range 3.670 GeV to 3.870 GeV. The data were taken with the SLAC-LBL Mark II magnetic detector at the e^+e^- storage ring SPEAR. The cross section results were fit to determine parameters of the $\psi(3770)$ resonance.

A detailed description of the Mark II detector may be found in Reference 4. Briefly, it is a 3 m diameter solenoidal magnet with a field of 0.4 Tesla. Charged particles are tracked by drift chambers over $0.85 \times 4\pi$ sr. Their identities may be established over restricted kinematic ranges by time-of-flight counters, liquid argon electromagnetic calorimeters and range counters (for π-μ separation). Photons are detected in the liquid argon calorimeter.

The detector trigger required at least two charged tracks be within the active volume of the drift chambers, with at least one within the central $0.65 \times 4\pi$ sr with a transverse momentum greater than 100 MeV/c.

Event selection for determination of the total hadronic cross section was essentially the same as that used in earlier SPEAR experiments.[5] Aside from time-of-flight criteria for rejecting cosmic rays, only the charged particle tracking information was used. Hadronic events were required to have 3 or more charged tracks with transverse momenta greater than 100 MeV/c, or 2 charged prongs of momenta greater than 300 MeV/c that were acoplanar with the incident e^+e^- beam direction by at least 20^o.

Contamination of the hadron sample from two-photon processes[6] and τ lepton pair production [7] were estimated by Monte Carlo calculations and were subtracted from the number of hadron candidates. The estimated two-photon contribution in the two-prong events was typically 6%; the overall two-photon event subtraction was typically 1%. Similarly, the τ contribution to the two-prong events was approximately 20% while only 8% of the total number of hadronic events are expected to come from $\tau^+\tau^-$ production.

Because the liquid argon calorimeter was unavailable during this running, corrections had to be made for contamination of the hadronic event sample by Bhabha scattering events that radiate energetic photons and subsequently produce e^+e^- pairs. These corrections were estimated by studying samples of data taken near the peak of the $\psi(3770)$ when the shower system was operational. A subtraction of 1% of the total number of hadron candidate events was made to account for this multiprong Bhabha contamination.

The average hadronic event detection efficiency was estimated from the observed charged multiplicity distributions and Monte Carlo simulations of this experiment using a phase space model and a D production model. The

estimates are both consistent with a smooth variation in the detection efficiency from 0.66 at E_{cm} = 3.67 GeV to 0.69 at 3.87 GeV.

Luminosity was measured by detection of small-angle Bhabha scattering events in counter telescopes centered at 22 mr from the incident beam direction. The system has been calibrated at other energies by comparison with the yield of Bhabha events in the central 0.65 x 4π sr of the detector.

During data taking, the storage ring energy was monitored with a precision flip coil in a reference bend magnet connected in series with the SPEAR bend magnets. The relative E_{beam} were held to within $\pm$0.2 MeV of the desired central value for data points in the range 1.835 GeV to 1.858 GeV and to within $\pm$ 0.4 MeV for the remaining data points presented. The systematic error on the energy scale (E_{cm}) of SPEAR is $\pm$0.13%.

The observed cross section results are presented in Figure 1a in terms of R, the ratio of the total hadronic cross section to the theoretical point-like cross section for muon pair production $\sigma_{\mu\mu}$ ($\sigma_{\mu\mu}$(nb)= 86.9 $/E_{cm}^2$ (GeV)). The most prominent features of the data presented in Figure 1a are the $\psi(3770)$ resonance and the radiative tail of the $\psi(3684)$. The error bars are statistical only; the overall systematic uncertainty is estimated to be $\pm$10% with contributions predominantly from event selection (5%), efficiency estimates (5%) and luminosity monitoring (7%).

The determination of the resonance parameters (mass $M_{\psi''}$, total width Γ_{tot}, and leptonic width Γ_{ee}) was accomplished by fitting the observed data to a function that described the resonance shape and the dominant non-resonant hadronic backgrounds, and included radiative corrections for the resonance itself, the nearby $\psi(3684)$ and $\psi(3095)$ and the continuum.[8,9] The resonance shape was taken to be a non-relativistic p-wave Breit-Wigner with an energy dependent total width ($\Gamma_{tot}(E_{cm})$):

$$R(E_{cm}) = \frac{1}{\sigma_{\mu\mu}} \frac{3\pi}{M^2_{\psi''}} \frac{\Gamma_{ee}\Gamma_{tot}(E_{cm})}{(E_{cm}-M_{\psi''})^2+\frac{\Gamma^2_{tot}(E_{cm})}{4}} . \qquad (1)$$

The form of Γ_{tot} was chosen assuming that $\psi(3770)$ is a resonance of unique isospin (0 or 1) which decays predominantly to D^+D^- or $D^o\bar{D}^o$ through the strong interaction. These assumptions are justified by its large previously measured total width (~25 MeV), proximity to the substantially narrower $\psi(3684)$, and its association with the onset of D meson production.(1) We therefore chose the energy dependence of the total width to account for both threshold dependence and the otherwise equal production of $D^o\bar{D}^o$ or D^+D^-:(10)

$$\Gamma_{tot}(E_{cm}) \propto \frac{p_+^3}{1+(rp_+)^2} + \frac{p_o^3}{1+(rp_o)^2} . \qquad (2)$$

Here p_+, p_o refer to the momentum of the pair-produced D^+, D^o, respectively, and are calculated using respective masses of 1863.3 and 1868.3 MeV.(11) The width $\Gamma_{tot}(E_{cm})$ in (2) is normalized to Γ_{tot} (the parameter of the fit) at the peak of the resonance ($E_{cm} = M_{\psi''}$) The parameter r is an interaction radius taken to be 2.5 fermi for the analysis. While the resonance parameters were found to be insensitive to the exact value of r, it does affect the charged-to-neutral decay fraction determined by (2). This variation is less than 5%, and is negligible in comparison to the uncertainties in total and leptonic widths.

The background shape includes a flat term and terms proportional to $(p_+)^3$ and $(p_o)^3$. The latter account for the onset of nonresonant D

production. Because of the proximity to threshold, these p^3 contributions are found to be negligibly small.

The radiative correction to the continuum amounts to ~9% (a constant R = 2.5 was assumed) and is subtracted before fitting the data. The radiative tails of the $\psi(3095)$ and $\psi(3684)$ have line shapes that depend only on their masses and leptonic widths.(8) The fit is not sensitive to the nearly flat contribution (~ 0.2 units of R) of the $\psi(3095)$ and, therefore, the previously measured values are used.(1) The fit is consistent with the known parameters of the $\psi(3684)$.(1) Finally, the self-radiative corrections for the $\psi(3770)$ were performed numerically in the fit.(8) At the peak, the correction amounts to an enhancement of ~ 25% of resonance height.

Figure 1b shows the radiatively corrected data and fit. The results for this fit are:

$$\begin{aligned} M_{\psi''} &= 3764 \pm 5 \text{ MeV} \\ \Gamma_{ee} &= 276 \pm 50 \text{ eV} \\ \Gamma_{tot} &= 23.5 \pm 5.0 \text{ MeV} \\ \chi^2 &= 12.4 \text{ for 17 degrees of freedom} \end{aligned} \qquad (3)$$

All errors in (3) reflect statistical as well as systematic uncertainties based on our cross section measurements and assumptions about signal and background shapes. The error in $M_{\psi''}$ includes the additional uncertainty (0.13%) in the absolute energy calibration of SPEAR. The error in $M_{\psi''}$ associated only with the fit is 1.9 MeV reflecting an insensitivity to background shapes and normalization of R.

Figure 2 shows the observed cross section with $\psi(3095)$ and $\psi'(3684)$ radiative tails and continuum background removed. The resonance is not corrected for self-radiative effects. It is therefore the measured cross section we attribute to D meson pair production. The value at the peak (E_{cm} = 3764 MeV) is found to be 9.3 ± 1.4 nb.

In Table I we compare these measurements with those of the two previous experiments.[1,2]

TABLE I

Comparison of $\psi(3770)$ Parameters				
Experiment	$M_{\psi''}$ (MeV)	Γ_{tot} (MeV)	Γ_{ee} (eV)	ΔM (MeV)
LGW[a]	3772 ± 6	28 ± 5	345 ± 85	88 ± 3
DELCO[b]	3770 ± 6	24 ± 5	180 ± 60	86 ± 2[c]
This Experiment	3764 ± 5	24 ± 5	276 ± 50	80 ± 2

a) See Reference 1.
b) See Reference 2.
c) See Reference 12.

The result we obtain for the partial leptonic width lies between the two earlier measurements. In the framework of the standard charmonium model[13] the magnitude of Γ_{ee} suggests the need for mixing of the $\psi(3684)$ and $\psi(3770)$ by continuum states in addition to the much smaller tensor force mixing of bound states.[3] We obtain a mixing angle of 20.3 ± 2.8^{o} for the two levels. The total width we obtain is in good agreement with both experiments. We find however a mass between 6 and 8 MeV lower than those experiments. The systematic error associated with the storage

ring calibration can be removed by measuring masses relative to the $\psi(3684)$. This mass difference (ΔM) is presented in Table I. Finally, we note that the peak cross section appears in reasonable agreement (about 10% lower) with the value 10.3 ± 2.5 nb reported earlier.[1]

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13. Here ψ(3684) is assigned the 2^3S_1 and ψ(3770) is assigned the 1^3D_1 level.

FIGURE CAPTIONS

1. (a) The observed cross section $R(=\sigma_{hadronic}/\sigma_{\mu\mu})$ with continuum radiative correction near the ψ(3770). The curve is the fit to the data.

   (b) The cross section in units of R after radiative corrections for ψ(3095), ψ(3684), and ψ(3770). The curve is the fitted Breit-Wigner.

2. The observed cross section for $D\bar{D}$ production.

TABLE CAPTION

$M_{\psi''}$ is the mass of the ψ'', Γ_{tot} the total width at the peak, and Γ_{ee} the partial leptonic width. ΔM is the mass difference of the ψ(3684) and the ψ(3770).

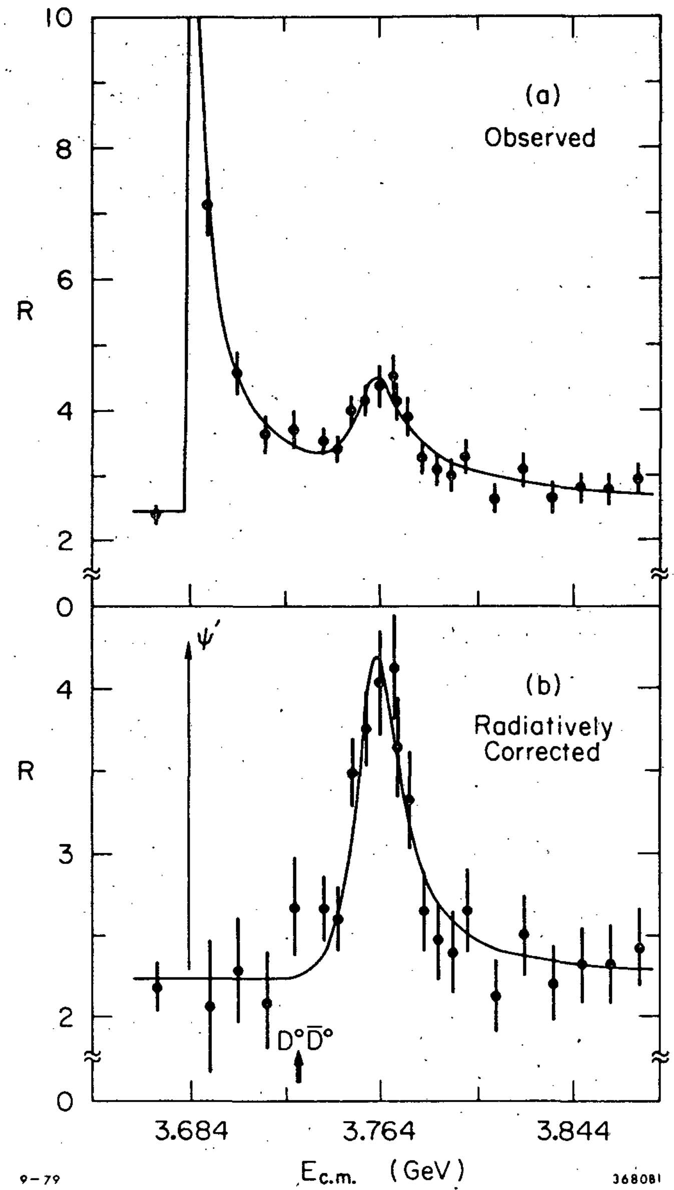

FIGURE 1

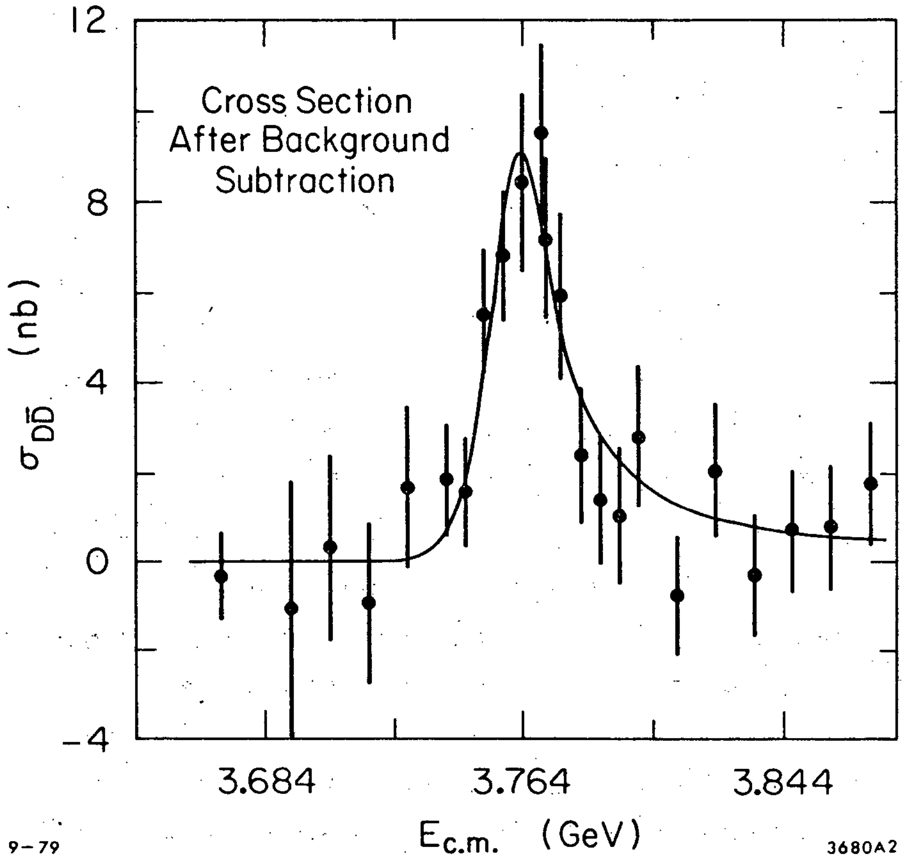
12
8
4
0
-4
Cross Section
After Background
Subtraction
$\sigma_{D\bar{D}}$ (nb)
3.684
3.764
3.844
$E_{c.m.}$ (GeV)
9-79
3680A2

FIGURE 2

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