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[1] L. Strawczynski, Ph.D. thesis, University of Rochester, 1974 (unpublished).

[2] The Coulomb field process was first discussed by H. Primakoff in connection with $\gamma+\gamma\to\pi^0$ [Phys. Rev. 81, 899 (1951)]. M. Good and M. Walker first discussed the general possibility of Coulomb field hadron dissociation [Phys. Rev. 120, 1855 (1960)].

[3] K. Foley *et al.*, Nucl. Instrum. Methods 108, 33 (1973).

[4] C. Bemporad *et al.*, Nucl. Phys. B33, 397 (1971); U. Kruse *et al.*, Phys. Rev. Lett. 32, 1328 (1974).

[5] Northwestern–Rochester–Carnegie Mellon Collaboration, to be published.

[6] T. A. Lasinski *et al.*, Rev. Mod. Phys., Suppl. 45, S1 (1973).

[7] cf. Ref. 1; C. Bemporad *et al.*, Nucl. Phys. B51, 1 (1973); G. Fäldt *et al.*, Nucl. Phys. B41, 125 (1972); S. Berman and S. Drell, Phys. Rev. 133, B791 (1964); A. Halprin, C. Anderson, and H. Primakoff, Phys. Rev. 152, 1295 (1966); L. Stodolsky, Phys. Rev. Lett. 26, 404 (1971).

[8] $C_0=13.7\pm2.2$ mb/(GeV/c)^4 at 5 GeV, D. J. Crennell *et al.*, Phys. Rev. Lett. 27, 1674 (1971). $C_0=6.9\pm1.5$ mb/(GeV/c)^4 at 16 GeV, J. Bartsch *et al.*, Nucl. Phys. B46, 46 (1972); an E^{-1} energy dependence has been assumed for extrapolation.

[9] W. Thirring, Phys. Lett. 16, 335 (1965); C. Becchi and G. Morpurgo, Phys. Rev. 140, B687 (1965); L. Soloviev, Phys. Lett. 16, 345 (1965); Y. Anisovitch *et al.*, Phys. Lett. 16, 194 (1965); A. Dar and V. F. Weisskopf, Phys. Lett. 26B, 670 (1968); L. M. Brown, H. Munczek, and P. Singer, Phys. Rev. Lett. 21, 707 (1968).

Discovery of a Second Narrow Resonance in e^+e^- Annihilation*†

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We have observed a second sharp peak in the cross section for $e^+e^-\to$ hadrons at a center-of-mass energy of 3.695 ± 0.004 GeV. The upper limit of the full width at half-maximum is 2.7 MeV.

The recent discovery of a very narrow resonant state coupled to leptons and hadrons[1-3] has raised the obvious question of the existence of other narrow resonances also coupled to leptons and hadrons. We therefore began a systematic search of the mass region accessible with the Stanford Linear Accelerator Center (SLAC) e^+e^- storage ring SPEAR and quickly found a second narrow resonance decaying to hadrons. The parameters of the new state [which we suggest calling $\psi(3695)$] are

$$M=3.695\pm0.004\text{ GeV},\quad \Gamma<2.7\text{ MeV}$$

[full width at half-maximum (FWHM)], where the mass uncertainty reflects the uncertainty in the absolute energy calibration of the storage ring.

The $\psi(3695)$, like the $\psi(3105)$, was found using the SLAC–Lawrence Berkeley Laboratory magnetic detector at SPEAR.[4] The luminosity monitoring, event acceptance criteria, and storage-ring energy determination have been described previously.[1]

The new feature of this run is the search procedure used to hunt for narrow e^+e^- resonances. In the search mode the storage-ring energy is increased in about 1-MeV steps ($E_{\text{c.m.}}=2\times E_{\text{beam}}$)

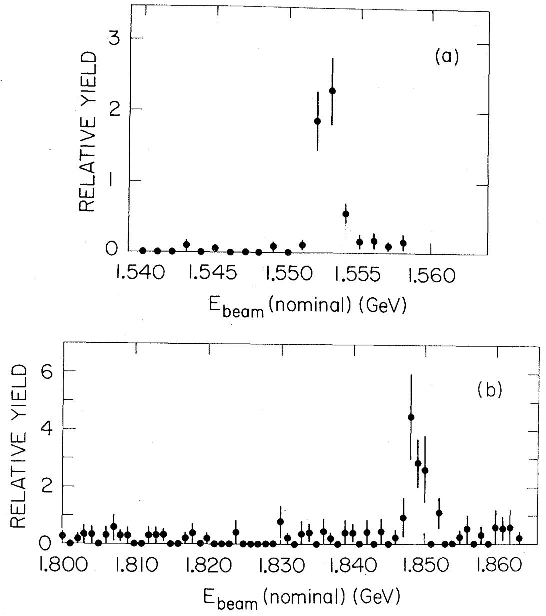

FIG. 1. Search-mode data (relative hadron yield) taken (a) in a 1-h calibration run over the $\psi(3105)$ (average luminosity of 2×10^{29} cm^{-2} sec^{-1}), and (b) during the run in which the $\psi(3695)$ was found (average luminosity of 5×10^{29} cm^{-2} sec^{-1}).

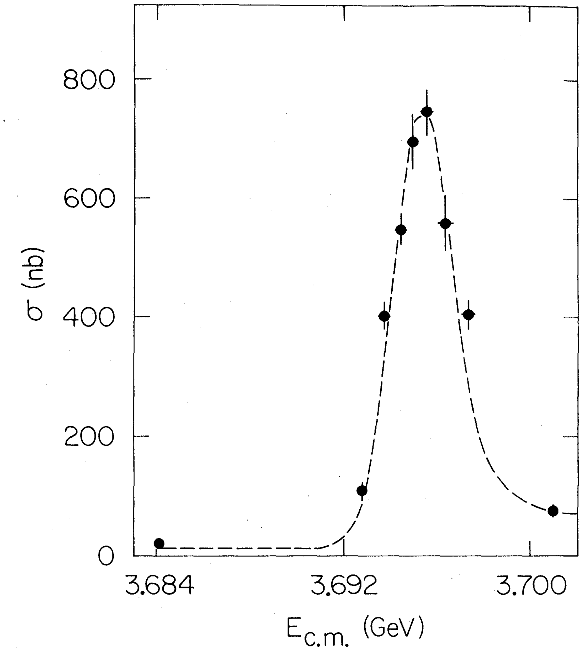

FIG. 2. Total cross section for $e^+e^- \to$ hadrons corrected for detection efficiency. The dashed curve is the expected resolution folded with the radiative corrections. The errors shown are statistical only.

every 3 min. The data taken during each step are analyzed in real time and the relative cross sections computed at the end of each step. Figure 1(a) shows the search-mode data taken during a calibration scan over the previously discovered $\psi(3105)$. Figure 1(b) shows the data taken during the first scan which began at a ring energy of 1.8 GeV. A clear indication of a narrow resonance with a mass of about 3.70 GeV is seen. It should be emphasized that we have not yet scanned any mass region other than that between 3.6 and 3.71 GeV.

On finding evidence of a resonance in the $e^+e^- \to$ hadron cross section, we switched to the normal SPEAR operating mode of longer runs at fixed energy. In this mode, smaller energy changes are possible than in the search mode. Figure 2 shows the cross section for $e^+e^- \to$ hadrons, corrected for the detection efficiency of about 55% over the energy region shown.

Our mass resolution is determined by the energy spread in the colliding beams, which depends on the energy of the beams. The expected Gaussian c.m. energy distribution ($\sigma = 1.2$ MeV) folded with the radiative processes[5] is shown as the dashed curve in Fig. 2. The width of the resonance must be smaller than this spread; thus, an upper limit to the FWHM is 2.7 MeV.

In summary, the colliding-beam data now show two narrow resonances in the hadron production cross section. Our determination of the parameters of the resonance are as follows:

	Mass (GeV)	Γ (FWHM) (MeV)
$\psi(3105)$	3.105 ± 0.003	<1.9 (Ref. 6)
$\psi(3695)$	3.695 ± 0.004	<2.7

We are continuing the search for others.

We thank the SPEAR operations staff for the technological *tour de force* they accomplished whereby we are able to scan the machine energy in small, well-defined steps. We also acknowledge the cooperation of the Stanford Center for Information Processing in expediting the computation needs of this experiment.

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[1] J.-E. Augustin *et al.*, Phys. Rev. Lett. 33, 1406 (1974).

[2] J. J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974).

[3] C. Bacci *et al.*, Phys. Rev. Lett. 33, 1408 (1974).

[4] J.-E. Augustin *et al.*, to be published.

[5] G. Bonneau and F. Martin, Nucl. Phys. B27, 321 (1971).

[6] In Ref. 1 a factor of $\sqrt{2}$ was omitted from the calculation of the experimental upper limit to the width of $\psi(3105)$. The correct value is 1.9 MeV rather than 1.3 MeV which appears in Ref. 1. However, the curve in Fig. 1(a) of Ref. 1 showing the calculated tail of the resonance is correct.

Determination of the Axial-Vector Form Factor in the Radiative Decay of the Pion*

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The branching ratio for the decay $\pi\rightarrow e\nu\gamma$ has been measured in a counter experiment in which the e^+ was detected in a magnetic spectrometer and the γ ray in a lead-glass hodoscope. From the measured branching ratio we determine γ, the ratio of the axial-vector form factor to the vector form factor. The latter is computed by using conserved-vector-current theory and τ_{π^0}, the π^0 lifetime. Adopting a best value 0.86×10^{-16} sec, we obtain $\gamma=0.15\pm0.11$ or $\gamma=-2.07\pm0.11$. A comparison between the measured values of γ and various theories is made.

Recent theoretical developments in quark models and current algebra have made it interesting to make a more accurate measurement of the axial-vector form factor of the pion radiative decay, $\pi\rightarrow e\nu\gamma$, first measured at CERN over ten years ago.[1] The general form for the radiative decay amplitude has been calculated by several authors.[2] The so-called inner-bremsstrahlung term (IB) arises from diagrams in which a photon is radiated from one of the charged, external lines of the ordinary decay $\pi\rightarrow e\nu$, and can be calculated from the observed rate of the decay $\pi\rightarrow e\nu$ by standard methods of quantum electrodynamics:

$$\frac{d^2W_{\mathrm{IB}}}{dx\,dy}=\frac{\alpha W_{e\nu}}{2\pi}\left(\frac{1-y}{x^2}\right)\left(\frac{(x-1)^2+1}{x+y-1}\right). \qquad (1)$$

In Eq. (1), $\alpha=1/137$, $W_{e\nu}$ is the rate of $\pi\rightarrow e\nu$, $x=2P_\gamma/m_\pi$, $y=2P_e/m_\pi$, and the rest mass of the electron has been set equal to zero.

The interesting effect is a structure-dependent (SD) process involving intermediate states generated by the strong interaction. These intermediate states are described by vector and axial-vector form factors, $a(q^2)$ and $b(q^2)$, which may be treated as constants because the momentum transfer in the decay is small. The equation for the SD rate is customarily written in terms of the vector form factor $a(0)$ and $\gamma\equiv b(0)/a(0)$:

$$\frac{d^2W_{\mathrm{SD}}}{dx\,dy}=\frac{(G\cos\theta)^2\alpha m_\pi^{\,7}|a(0)|^2}{64\pi^2}\times[D(1+\gamma)^2+E(1-\gamma)^2]. \qquad (2)$$

Here G is the weak coupling constant, θ is the Cabibbo angle, $D=(1-x)(x+y-1)$, and $E=(1-x)\times(1-y)^2$. The SD-IB interference term is small and is neglected.

The experimental layout is shown in Fig. 1. With the low-energy achromatic pion beam at the Berkeley 184-in. cyclotron, about 2×10^5 π^+/sec were stopped in a counter hodoscope, which was slanted to increase the stopping material and to minimize the positron energy loss. The positron momentum was measured in the magnet–spark-chamber spectrometer system with a resolution of about 2 MeV. Momentum normalization and resolution were determined by fitting the end point in the momentum spectrum of positrons from μ decay and by triggering the system occasionally on the monoenergetic positrons from $\pi^+\rightarrow e^+\nu$.