scalar mesons in the adjoint representation of SU(N) which arise from iterated bubble graphs. For the mesons to acquire (different) masses it requires mechanisms for conventional breaking of SU(N) symmetry [hence explicitly breaking SU(N)$\otimes$ SU(N)] as treated, for example, in the Gell-Mann–Oakes–Renner model.[7]

It is a pleasure to thank C. G. Callan for suggesting the problem and for many enlightening discussions. The author is also grateful for stimulating and beneficial conversations with R. F. Dashen and also D. J. Gross.

(a)Work supported in part by the National Science Foundation.

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Search for Narrow Resonant States in e^+e^- Collisions near 6 GeV

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(Received 4 February 1977)

Following reports of anomalous dielectron prediction in the mass region near 6 GeV at 400 GeV, we searched for an enhancement in the reaction $e^+e^- \to$ hadrons and $e^+e^- \to e^+e^-$ at SPEAR in the center-of-mass energy range 5.67–6.43 GeV. The leptonic and hadronic cross sections show no statistically significant peaks. In this mass range, 95% confidence level upper limits for the decay width into electron pairs are less than 200 eV for a narrow resonance which decays predominantly either into hadrons or into electron pairs.

Following reports of an enhancement near 6 GeV in the invariant-mass spectrum of e^+e^- pairs produced in high-energy hadron-hadron collisions,[1,2] we measured the e^+e^- total cross section in 4-MeV intervals in the center-of-mass energy range 5.67 to 6.43 GeV, using the SPEAR electron-positron colliding-beams machine. The detector triggered on both charged and neutral particles. An integrated luminosity of about 10 nb^{-1} was obtained in each energy interval, corresponding to about 75 observed hadronic events. The sensitivity to narrow resonances was about

10 times greater than a previous scan.[3,4]

As we describe below, our detector triggered on the presence of two or more charged-particle tracks within 90% of the full solid angle, together with the deposition of 150 MeV of energy from *either* neutral or charged particles, and was therefore subject to quite different systematic errors and independent statistical errors from a scan made at the same time in the opposite interaction region, where the Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory magnetic detector[5] was triggered on events where at least two charged tracks entered their acceptance which was about 65% of the total solid angle. Since our detector demanded an energy deposition, it was sensitive to the possible presence of a resonance with unusual decay modes, such as one with predominant neutral channels.

Figure 1 shows the apparatus. Four cylindrical layers of 1-cm-square proportional tube counters, 60 cm long, surrounded the SPEAR east interaction region. A rectangular box of proportional wire chambers (PWC) enclosed the tube counters. Two stacks of hexagonal NaI crystals covered the top and bottom sides of the box. The tube counters, with wires parallel to the colliding-beam direction, measured the azimuthal angle of charged tracks to $\pm 3°$ over 0.90 of the full 4π solid angle. Each face of the PWC box contained three planes of wires running transverse to the beams, with an active region of 35 cm×35

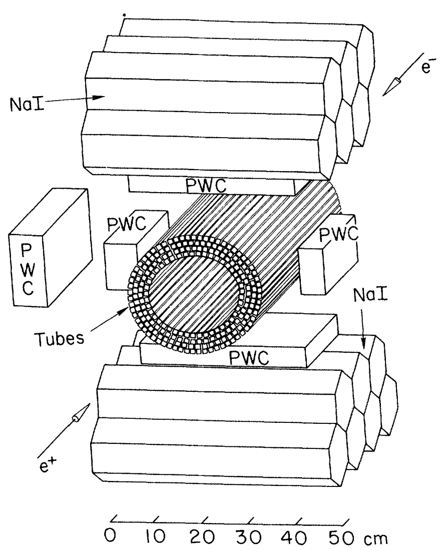

FIG. 1. Diagram of apparatus showing proportional-tube counter array and box of proportional wire chambers planes (PWC) surrounding the interaction region, and the stacks of Na(I) crystal detectors.

cm, providing charged-particle tracking over 0.35 of 4π. The stacks of NaI crystals gave good detection capability for both charged and neutral particles. The top stack had six crystals and the bottom had seven. Each crystal was a hexagonal prism, 50 cm long, 15 cm between vertices. These stacks provided triggering capability over 0.20 of 4π. Four other arrays of NaI crystals placed within 3° of the beam axis monitored low-angle Bhabha scattering and measured the luminosity to $\pm 5\%$ absolute accuracy.

Hadronic events were selected by requiring that there be two or more well-defined tracks in the tube counters, more than 150 MeV of energy deposited in either NaI stack, and a vertex reconstruction to within a ± 10 cm of the interaction region for events with tracks in the PWC box. Further cuts eliminated cosmic rays and track topologies known to be associated with machine background and beam-pipe scatters. The major leptonic backgrounds were eliminated by requiring that all two-track events were acoplanar by more than 40°, and that less than 0.67 of the single-beam energy was deposited in each NaI stack. We estimate the background in the hadron sample to be less than 4%. Assuming a charged-plus-neutral multiplicity of 7, we estimate the average detection efficiency for hadronic events to be 0.67 ± 0.10. The average behavior of the cross-section measurement agrees well with other results.[3] The systematic error in this efficiency represents the uncertainty in estimating the energy deposited in the NaI stacks by the charged hadrons, together with the effect of changing machine-induced backgrounds (such as scattering from quadrupoles and the beam pipe, and beam-gas scattering) on the trigger efficiency.

We have also measured the $e^+e^- \to e^+e^-$ cross section around 90°. The NaI stacks were 10 irradiation lengths deep, and provided good energy resolution for electron detection. These dielectron events were selected by requiring that greater than 0.67 of the single-beam energy was deposited in both stacks, and that there were two tracks coplanar within 40°. For these events our solid-angle acceptance was $|\cos\theta| < 0.5$ and $|\cos\varphi| < 0.6$, where θ is the polar angle measured from the beam line, and φ is the azimuth measured from the normal to the ring.

Figure 2 shows the cross section for $e^+e^- \to$ hadrons, and a cross section for $e^+e^- \to e^+e^-$ derived by extrapolating the counting rate into our detector acceptance to that into the full solid angle us-

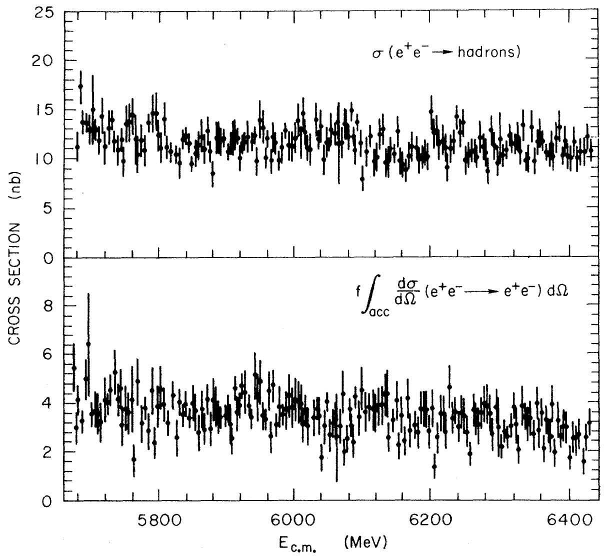

FIG. 2. Cross sections in the range $E_{\mathrm{c.m.}}=5.7$ to 6.4 GeV for $e^+e^- \rightarrow$ hadrons and $e^+e^- \rightarrow e^+e^-$. The electron-positron pair cross section is obtained by multiplying the cross section into our detector acceptance by a factor f to extrapolate to the full solid angle. We assumed a $(1+\cos^2\theta)$ dependence, characteristic of a spin-1 resonance. f is then 8.0.

ing a $1+\cos^2\theta$ angular dependence. The cross sections show fluctuations that are not due to statistics, and are caused by small systematic effects, such as changing machine-induced backgrounds that have not been fully eliminated from the data. The effect of such systematics has been included in the quoted upper limits.

The observed line shape of a resonance at a storage ring is given by a convolution of the natural linewidth, the beam-energy profile function, and the radiative effects. At SPEAR the beam energy has a Gaussian profile with $\sigma=2.8$ MeV at 6 GeV center-of-mass energy.[6] The integrated area of the peak in the observed cross section for a Breit-Wigner resonance with width much smaller than that of the beam-energy spread is

$$\int \sigma_{\mathrm{final}}\, dE = \frac{2\pi^2(2J+1)}{M^2}\,\frac{\Gamma_e\Gamma_f}{\Gamma},$$

where the resonance has spin J, mass M, and partial widths Γ_f into the final state and Γ_e into electrons, and E is the center-of-mass energy. If the hadronic decay modes predominate, then $\Gamma_h/\Gamma \approx 1$, whereas if the leptonic modes predominate then $\Gamma_e=\Gamma_\mu$ and $\Gamma_e/\Gamma\approx 0.5$. In both cases Γ_e can be extracted from the data. In order to look for possible narrow resonant states, the cross sections were fitted by the form

$$\sigma = a + bE + c\,\frac{\Gamma_f/2\pi}{(E-M)^2+\Gamma_f^2/4},$$

where a and b describe the nonresonant background, Γ_f is the total observed width, including beam-energy dispersion, and c is the area under the resonance, which is assumed to be $J=1$. For a very broad resonance, we can derive the branching ratio B into electron pairs from the formula for the peak cross section of a Breit-Wigner resonance,

$$\sigma_{\mathrm{peak}} = \frac{\pi(2J+1)}{M^2}\,\frac{\Gamma_e/\Gamma_h}{\Gamma^2/4}.$$

If hadronic decay modes predominate, then $\Gamma_h/\Gamma \approx 1$, and we can extract $B_e=\Gamma_e/\Gamma$.

We have used our data to set 95%-confidence-level upper limits for the existence of possible resonances. Radiative corrections have been ap-

TABLE I. Radiatively corrected 95%-confidence-level upper limits on Γ_e and B_e for a possible resonance with predominantly hadronic decay modes.

Γ (MeV)	0	10	30	50	> 100
Mass (GeV)	Γ_e (eV)	Γ_e (eV)	Γ_e (eV)	Γ_e (eV)	$10^6 B_e$
5.7–5.8	90	147	160	187	8.4
5.8–5.9	27	38	15	26	4.4
5.9–6.0	65	96	153	182	4.0
6.0–6.1	69	132	202	246	6.0
6.1–6.2	65	102	109	144	3.3
6.2–6.3	71	126	148	165	3.2
6.3–6.4	51	77	118	154	3.0

TABLE II. Radiatively corrected 95%-confidence-level upper limits on Γ_e for a possible narrow resonance decaying predominantly into an e^+e^- pair.

Mass (GeV)	Γ_e (eV)
5.7–5.8	126
5.8–5.9	77
5.9–6.0	143
6.0–6.1	121
6.1–6.2	159
6.2–6.3	148
6.3–6.4	182

plied in accordance with well-known prescriptions[7,8] and increase the quoted upper limits by a factor of about 1.4 over those extracted from the raw data. Table I shows limits on Γ_e and B_e for a resonance with predominantly hadronic decay modes. For a resonance with width $\ll 10$ MeV, the upper limit on Γ_e is 90 eV. B_e is $< 10^{-5}$ throughout our mass region. Table II shows the limits on Γ_e for a possible narrow resonance which decays predominantly into an e^+e^- pair. We set an upper limit of 182 eV on Γ_e.

We conclude that if a narrow state exists in this mass region then either it has a small coupling to e^+e^- pairs, or it has an unusual decay mode to which our detector is insensitive. We note that a recent search found no enhancement near 6 GeV in the mass spectrum of dimuons produced in high-energy hadron collisions.[9]

[a]Supported by National Science Foundation Grants No. MPS 71-02657 and No. MPS 75-19166.

[b]Supported by Istituto Nazionale di Fisica Nucleare (Italy).

[c]Supported by U. S. Energy Research and Development Administration.

[d]Supported by National Science Foundation Grant No. MPS 72-04426.

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Accurate Determination of the ^{3}He-*dp* and ^{3}He-*d*p* Coupling Constants[a]

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(Received 6 May 1977)

From a forward dispersion relation applied to $p+d$ and $p+{}^3$He scattering amplitudes we obtain accurate empirical values for the ^{3}He-dp and ^{3}He-d^*p coupling constants. The corresponding asymptotic normalization parameters for the S-state wave-function component of ^{3}He are found to be $C^2(^3\text{He}, dp) = 3.40 \pm 0.20$ and $C^2(^3\text{He}, d^*p) = 5.85 \pm 0.25$.

The ^{3}H-dn and ^{3}He-dp coupling constants or the corresponding asymptotic normalizations C^2 for the S-state wave functions of ^{3}H and ^{3}He are basic trinucleon bound-state parameters with a status[1] similar to the binding energies and the charge radii. From the review of Kim and Tubis[1] one concludes that $C^2(^3\text{H}, dn) \approx C^2(^3\text{He}, dp) \approx 2.9 \pm 0.5$ for the N-d portions of the trinucleon center-of-mass wave function, in agreement with more recent investigations.[2-4] Kim and Tubis point out that accurate empirical values might discriminate between NN interactions which differ for nucleon separations of 1–3 fm.

We report a forward dispersion relation (FDR) analysis of $p+d$ and $p+{}^3$He scattering data which yields reliable information on $C^2(^3\text{He}, dp)$ and —for the first time—on the corresponding quantity $C^2(^3\text{He}, d^*p)$ for the p-$np(^1S_0)$ portion of the ^{3}He wave function. Compared to other methods[1-5] used to extract nuclear coupling constants (as pole residues of scattering or reaction amplitudes) from empirical data, the FDR approach combines several decisive advantages. Apart from Coulomb corrections it is model independent, since it is based on accepted conjectures about fundamental symmetries and the analyticity of amplitudes. It eliminates the large contributions of the positive-energy (continuum) scattering states before an extrapolation to the poles of interest is performed. If necessary it can be combined with conformal mapping techniques.[6] In addition, the analytic structure of the forward scattering amplitude is simple because of the lack of angular momentum projection cuts. Finally, the application of an FDR to linear combinations of amplitudes connecting specific initial and final