Limits on Charmed-Meson Production in e^+e^- Annihilation at 4.8-GeV Center-of-Mass Energy[*]

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Data from e^+e^- annihilation into hadrons at 4.8 GeV center-of-mass energy were used to search for charmed mesons in the mass range 1.5 to 4.0 GeV/c^2. We looked for narrow peaks in the invariant-mass distributions for $K^\mp\pi^\pm$, $K_s^0\pi^+\pi^-$, $\pi^+\pi^-$, K^+K^-, $K^\mp\pi^\pm\pi^\pm$, $K_s^0\pi^\pm$, $K_s^0K^\pm$, and $\pi^+\pi^-\pi^\pm$. We present upper limits for the inclusive production cross section times the branching ratio for charmed mesons having these decay modes.

Since the discoveries of the $\psi(3095)$,[1] the $\psi(3684)$,[2] and the broad enhancement[3] at 4.15 GeV center-of-mass energy ($E_{\text{c.m.}}$) in the total cross section for e^+e^- annihilation into hadrons, there has been renewed interest in determining whether the increase in $R=\sigma(e^+e^-\to\text{hadrons})/\sigma(e^+e^-\to\mu^+\mu^-)$ is associated with the onset of charmed-particle[4-7] production.

In order to search for inclusive production of charmed mesons, we looked for narrow peaks in the invariant-mass distributions of the following combinations of particles: $K^\mp\pi^\pm$, $K_s^0\pi^+\pi^-$, $\pi^+\pi^-$, K^+K^-, $K^\mp\pi^\pm\pi^\pm$, $K_s^0\pi^\pm$, $K_s^0K^\pm$, and $\pi^+\pi^-\pi^\pm$. These are expected to be dominant decay modes of the conjectured charmed mesons D^+, D^0, and F^+.[4,7-11]

We have used the data from hadron production by e^+e^- annihilation at $E_{\text{c.m.}}=4.8$ GeV taken with the Stanford Linear Accelerator Center (SLAC)–Lawrence Berkeley Laboratory solenoidal magnetic detector at the SLAC electron-positron colliding-beam facility SPEAR. The detector, trigger requirements, and the selection of events from e^+e^- annihilation into hadrons have been described previously.[3,12] The data sample consisted of 9914 hadronic events taken with an integrated luminosity of 790 nb^{-1}.

All particles associated with an event vertex were used in forming the combinations. For the $\pi^+\pi^-$ and $\pi^+\pi^-\pi^\pm$ combinations and the K^+K^- combinations each particle was assumed to have the mass of a charged pion or a charged kaon. For $K^\mp\pi^\pm$ the combination was entered twice in the mass histogram—once for each of the two possible particle-mass assignments. For $K^\mp\pi^\pm\pi^\pm$ combinations the particle with charge opposite that of the other two particles in a three-particle, ±1-charge combination was assigned a kaon mass. No attempt was made to identify charged kaons by time of flight since such identification was not reliable for particles with momentum greater than 600 MeV/c. Combinations containing a K_s^0 were formed by finding pairs of oppositely charged particles having invariant mass between 470 and 520 MeV/c^2 assuming pion masses and then including with this pair one or two other particles which were assumed to have pion or kaon masses. A distinct K_s^0 signal was observed with a signal-to-background ratio of 0.25 ± 0.03. The observed invariant-mass distributions are shown in Figs. 1 and 2.

The invariant-mass resolutions and detection efficiencies for particles having the decay modes considered were calculated by use of a Monte Carlo program which incorporated the geometric acceptance, the trigger efficiency, and all other known inefficiencies of the detector. The momentum resolution due to measurement error and multiple Coulomb scattering, which was determined to be $\sigma(p)/p=1.6p\%+0.6\%$ added in quadrature, where p is the momentum in GeV/c, was also included. The charmed mesons were assumed to be produced with angular and momentum distributions as given by Lorentz-invariant phase space and to decay isotropically. The de-

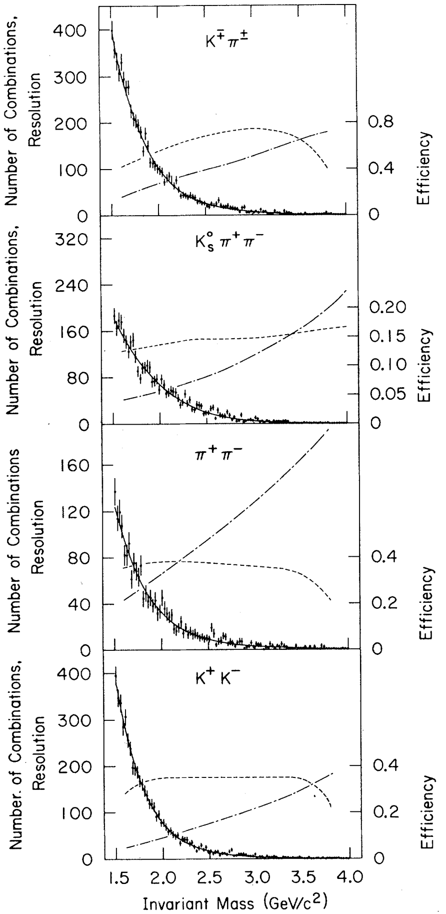

FIG. 1. Observed invariant-mass distributions in 25-MeV/c^2 bins for charge-0 combinations. The solid lines represent smooth curves fitted to the data. The detection efficiency (dashed curve) and measurement resolution in units of MeV/c^2 (dash-dotted curve) are also indicated. The left-hand scale is used for the number of combinations and the resolution and the right-hand scale is used for the efficiency.

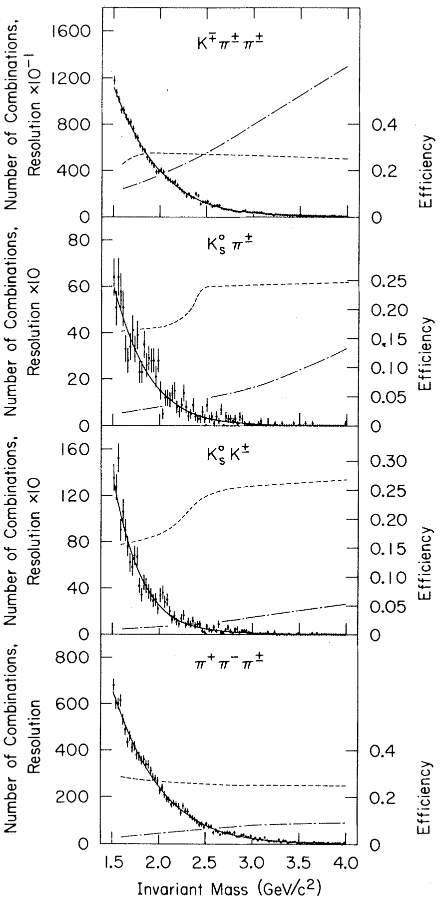

FIG. 2. Observed invariant-mass distributions in 25-MeV/c^2 bins for charge-±1 combinations. The solid lines represent smooth curves fitted to the data. The detection efficiency (dashed curve) and measurement resolution in units of MeV/c^2 (dash-dotted curve) are also indicated. The left-hand scale is used for the number of combinations and the resolution and the right-hand scale is used for the efficiency.

tection efficiency was taken to be the number of particles detected with mass within the measurement resolution (full width at half-maximum, FWHM) of the true mass. with background subtracted, divided by the number of particles produced. For K_s^0's the efficiency included the branching ratio for $K_s^0 \to \pi^+\pi^-$. The efficiencies and mass resolutions are indicated in Figs. 1 and 2. The efficiencies used were the lower limits obtained after considering the effects of binning and the effects of different assumed modes of charmed-meson production (e.g., D^+D^- and $D^+D^- + n\pi$).

We found no convincing narrow peaks in the invariant-mass distributions. The particles for which we are searching were assumed to have decay widths much less than our mass resolutions. Two 4-standard-deviation peaks were observed —at 2.05 GeV/c^2 in $K_s^0K^\pm$ and at 2.40 GeV/c^2 in $K^\mp\pi^\pm\pi^\pm$. There was no evidence for these peaks in the approximately 2500 hadronic events at $E_{\text{c.m.}} = 5.0$ GeV.

Upper limits on the inclusive cross section for the production of a charmed meson times the branching ratio to the decay mode considered were calculated. The background was estimated by fitting a smooth curve to each mass distribution. The fitted curves are represented by the solid lines in Figs. 1 and 2. We calculated 90%-confidence-level upper limits for the number of

TABLE I. Largest upper limits at the 90% confidence level for inclusive production cross section times branching ratio, in nanobarns, for various mass regions.

Decay mode	Mass Region (GeV/c^2) 1.50–1.85	1.85–2.40	2.40–4.00
$K^-\pi^+$ and $K^+\pi^-$	0.25	0.18	0.08
$K_s{}^0\pi^+\pi^-$	0.57	0.40	0.29
$\pi^+\pi^-$	0.13	0.13	0.09
K^+K^-	0.23	0.12	0.10
$K^-\pi^+\pi^+$ and $K^+\pi^-\pi^-$	0.51	0.49	0.19
$K_s{}^0\pi^+$ and $K_s{}^0\pi^-$	0.26	0.27	0.09
$K_s{}^0K^+$ and $K_s{}^0K^-$	0.54	0.33	0.09
$\pi^+\pi^-\pi^+$ and $\pi^+\pi^-\pi^-$	0.48	0.38	0.18
$K^\mp\pi^\pm$, $\bar{K}^0\pi^+\pi^-$, and $K^0\pi^+\pi^-$	1.16	0.90	0.58
K^+K^- and $\pi^+\pi^-$	0.23	0.16	0.15
$K^\mp\pi^\pm\pi^\pm$, $\bar{K}^0\pi^\pm$, and $K^0\pi^\pm$	0.64	0.51	0.30
$\bar{K}^0K^\pm$, $K^0K^\pm$, and $\pi^+\pi^-\pi^\pm$	1.10	0.76	0.29

combinations above background in each group of adjacent bins as determined by the FWHM mass resolution. Each upper limit for a number of combinations was converted to an upper limit for cross section times branching ratio by dividing by the efficiency and the integrated luminosity. In Table I we present the largest 90%-confidence upper limit for each of the decay modes for each of three mass regions: 1.5 to 1.85, 1.85 to 2.4, and 2.4 to 4.0 GeV/c^2. The mass region of particular interest for the production of charmed mesons ranges from 1.85 [half the mass of the $\psi(3684)$] to 2.4 GeV/c^2 (half of $E_{\text{c.m.}}$) since charmed mesons are expected to be produced in charmed-anticharmed pairs. We have also calculated combined largest 90%-confidence-level upper limits for pairs of mass distributions in which the combinations have the same charge and assumed strangeness. In this case we have used efficiencies for combinations including K^0 or $\bar{K}^0$ which are one half the efficiencies for the $K_s{}^0$ combinations. The combined upper limit can be less than either of the individual upper limits if dips in one mass distribution occur at the same masses as peaks in the other distribution. The combined upper limits are also listed in Table I.

If one assumes that all of the increase in R is due to charmed-meson production, these limits are inconsistent with models in which the lowest-mass charmed mesons decay nonleptonically according to a conventional current-current weak interaction.[4-11] The dominant decays of the lowest-mass charmed mesons are expected to be nonleptonic decays into two and three hadrons.[7,8,13] For charmed mesons of 2-GeV/c^2 mass the branching ratios for these decays are estimated[14] to add up to approximately 80% after allowing for a 10% branching ratio into leptonic and semileptonic modes.[7] The excess hadron cross section above the three-color-quark-model prediction of a constant $R = 2$ is 10.7 ± 1.5 nb at $E_{\text{c.m.}} = 4.8$ GeV.[3] If this cross section is due to production of pairs of charmed mesons resulting in equal cross sections for $e^+e^- \to D^+$ (or D^-) + anything, $e^+e^- \to F^+$ (or F^-) + anything, and $e^+e^- \to D^0$ (or $\bar{D}^0$) + anything, the cross section for inclusive production of D^+ or D^-, for example, would be 7.1 nb. Of the two-body decay modes of D^+, the dominant mode is expected to be $\bar{K}^0\pi^+$,[7,9] although this mode may be suppressed as it is in the limit of exact SU(3).[7,8] Of the three-body decays of D^+, the dominant modes are expected to be[7,8] $K^-\pi^+\pi^+$, $\bar{K}^0\bar{K}^0K^+$, $\bar{K}^0\pi^+\eta$, and $\bar{K}^0\pi^+\pi^0$ which would occur in the ratio[15] 4:4:3:1 (without correcting for phase space). Our combined upper limit for $\bar{K}^0\pi^\pm$, $K^0\pi^\pm$, and $K^\mp\pi^\pm\pi^\pm$ is 0.51 nb which gives an upper limit on the branching ratio of

$$\frac{\Gamma(D^+ \to \bar{K}^0\pi^+ \text{ or } K^-\pi^+\pi^+)}{\Gamma(D^+ \to \text{all})} < \frac{0.51 \text{ nb}}{7.1 \text{ nb}} = 7.2\%.$$

This upper limit on the D^+ branching ratio into $\bar{K}^0\pi^+$ and $K^-\pi^+\pi^+$ is at least a factor of 3 lower than estimates based on the conventional phenomenological model.[14]

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[1] J.-E. Augustin *et al.*, Phys. Rev. Lett. 33, 1406 (1974); J. J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974).

[2] G. S. Abrams *et al.*, Phys. Rev. Lett. 33, 1453 (1974).

[3] J.-E. Augustin *et al.*, Phys. Rev. Lett. 34, 764 (1975).

[4] J. D. Bjorken and S. L. Glashow, Phys. Lett. 11, 255 (1964).

[5] S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D 2, 1285 (1970).

[6] S. L. Glashow, in *Experimental Meson Spectroscopy —1974*, edited by D. A. Garelick, AIP Conference Proceedings No. 21 (American Institute of Physics, New York, 1974).

[7] M. K. Gaillard, B. W. Lee, and J. L. Rosner, Rev. Mod. Phys. 47, 277 (1975).

[8] G. Altarelli, N. Cabibbo, and L. Maiani, Ecole Normale Supérieure Report No. PTENS 74/5 (to be published).

[9] R. L. Kingsley, S. B. Treiman, F. Wilczek, and A. Zee, Phys. Rev. D 11, 1919 (1975).

[10] A. Pais and V. Rittenberg, Phys. Rev. Lett. 34, 707 (1975).

[11] M. H. Einhorn and C. Quigg, Fermilab Report No. FERMILAB-Pub-75/21-THY (unpublished).

[12] J.-E. Augustin et al., Phys. Rev. Lett. 34, 233 (1975).

[13] The average charged-particle multiplicity in e^+e^- annihilation into hadrons rises slowly from $E_{\text{c.m.}} = 2.4$ GeV to $E_{\text{c.m.}} = 5.0$ GeV. Therefore one would not expect the rise in R to be due to production of charmed mesons which have large branching ratios for decays into four or more hadrons.

[14] See Table IV of Ref. 7.

[15] H. Harari, private communication.

Quasielastic Electron Scattering and Giant Multipole Resonances in ^{116}Sn

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Electron-^{116}Sn scattering spectra were obtained over an excitation energy range of about 100 MeV. The experimental transverse spectrum is in good agreement with the Fermi-gas model, but not the longitudinal spectrum. The quasielastic contribution was then obtained from the shape of the transverse spectrum. The residual amount interpreted to be the resonance part was divided into many multipoles.

Inelastic scattering of electrons and hadrons from the nuclear continuum for a wide range of nuclei has revealed the existence of giant multipole resonances (GMR).[1] The GMR appear as bumps riding on a large continuous background. Accordingly major uncertainties in the GMR data arise from the approximations used for the background. In order to estimate this background, as a first step, the procedure of subtracting the contributions due to the electrons degraded through radiative effects is used. Then the quasielastic-electron-scattering contributions arising from electron collisions with the individual nucleons in the nucleus must be subtracted. However, since the same processes are involved in the GMR as for quasielastic scattering these two effects have not been considered to be distinct.[2,3]

Quasielastic electron scattering (QES) is a simple knockout reaction, which involves the proton and neutron form factors. In this process the longitudinal (charge) and transverse (magnetic) form factors are therefore comparable in magnitude, while in the collective electric multipole excitations the transverse form factor is reduced approximately to a fraction $(\omega/q)^2$ of the longitudinal form factor, where ω is the excitation energy and q is the momentum transfer.

According to the result[4] of 180° electron scattering from ^{197}Au in which only transverse terms contribute, the $M1+M3$ peak with a width of ~ 3 MeV has been observed at ~ 8 MeV while no indications have been found at the expected energies of the GMR. We infer that the transverse form factor is the sum of the individual excitations