K° PRODUCTION IN e+e- ANNIHILATION*

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The production of enutral kaons in e+e- annihilation has been measured for c.m. energies between 3.4 GeV and
7 6 GeV. Near 4 GeV the inclusive K_S cross section shows an increase and structure similar to total hadron production. Roughly 40—45% of all hadronic final states contain kaons, except at 4 028 GeV and 4.415 GeV, where a significantly larger kaon fraction is observed

The study of inclusive kaon production by e+e-
annihilation can be used as a probe for the production
of charmed particles, provided the charmed quark decays preferentially to the strange quark as predicted
by weak interaction theory [1]. In this paper we report measurements of the inclusive neutral kaon production at c.m. energies between 3.4 GeV and 7.6 GeV.
The observed kaon yield shows an energy dependence
that closely resembles that of the total hadronic cross
section [2—5].

The experiment is based on data recorded by the
SLAC-LBL magnetic detector at the e+e- storage
ring SPEAR. The apparatus and the data-taking procedures have been described previously [6]. The analysis
uses hadronic final states with three or more detected
charged particles. The particle trajectories are reconstructed using four sets of cylindrical spark chambers,
two graps each, with radii between 65 cm and 135 cm,
and a pair of proportional wire chambers at radii of
17 cm and 22 cm. The proportional chamber information is limited to the azimuthal coordinate ϕ with a
resolution of 3.5 mrad. In this analysis the tracks are
not constrained to originate from the beam. The corresponding momentum resolution is $\Delta p/p = 0.022 p$
(GeV/c).

Neutral kaons are identified by their decay $K_S \to
\pi^+ \pi^-$. In order to identify this decay and to suppress
background from pions produced directly, the following
procedure has been used. First, the event is projected
onto the x-y plane, i.e., the plane perpendicular to the
beams, and for any pair of oppositely charged particles
the intersection of the tracks is determined. In order
to assure good resolution on the vertex position the
projected angle between the tracks is required to be at
least 10° and no more than 170°. In general, one finds
two intersections; the unphysical solution is usually
far outside the detector and is eliminated by a cut on
the distance from the beam. A minimum of 10 mm,
corresponding to roughly four standard deviations
away from zero, and a maximum of 16 cm, which is
just inside the first wire chamber, is required. The
vertex position obtained in projection is checked using
the third coordinate. Tracks that are separated at the
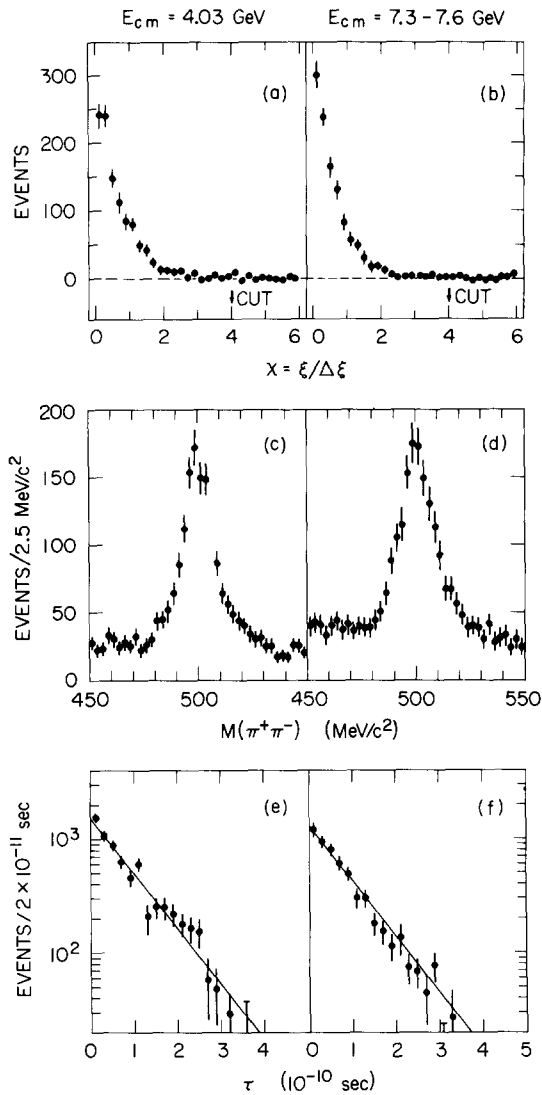intersection by more than 16 cm with respect to z are
rejected.

Fig. 1. Identification of the decay $K_S^0 \rightarrow \pi^+\pi^-$ in hadronic final states produced at 4.028 GeV and above 7.3 GeV c.m. energy: a, b) $\chi = \xi/\Delta\xi$ distribution of the angle ξ (defined in the text) for K_S candidates selected by cuts on the vertex position and opening angle. Background estimated from the mass distribution has been subtracted. The cut in ξ is applied at $\chi = 4$. c, d) effective mass of the pion pairs; e, f) lifetime distributions for K_S candidates with background subtracted. The line is expected decay distribution.

For the pairs selected in this way the total momentum is calculated as the vector sum of the momenta of the two tracks at the intersection. This vector is required to point back to the beam intersection. This is

achieved by a four standard deviation cut on ξ, the angle between the momentum and the vector pointing from the beam to the vertex, as illustrated in fig. 1a, b. This cut greatly enhances the signal to background ratio.

The effective mass distributions of pion pairs satisfying the above criteria are presented in fig. 1c, d for data at two different c.m. energies. We obtained very similar results at all other energies under study. The observed width of 18 MeV/c^2 (FWHM) is compatible with the estimated resolution. The background below the peak has been estimated from mass bins on both sides of the signal and will be subtracted in the following analysis. For a 40 MeV/c^2 wide interval centered on the K^0 mass the signal to background ratio amounts to roughly 2.5. To check the background subtraction we have studied the distribution of the lifetime τ measured in the K^0 rest system. We define τ as $\tau = (l - l_{min})m_K/p_K$, where l is the decay path length and $l_{min} = 10$ mm corresponds to the cut-off, m_K denotes the mass and, p_K the momentum of the K^0. The background subtracted lifetime distributions agree well with the known lifetime, as shown in fig. 1e, f. It should be noted that the background events are strongly peaked near $\tau = 0$, the background to signal ratio in the first bin is of the order of one, decreases rapidly to a few percent, and then rises to almost one for $\tau > 5 \times 10^{-10}$s.

The momentum spectra of the detected $K_S \rightarrow \pi^+\pi^-$ decays are corrected for detection efficiency. This is evaluated by Monte Carlo techniques. We define the probability of detecting a decay $K_S \rightarrow \pi^+\pi^-$ as $\epsilon(p_K, E_{cm}) = \epsilon_0 \cdot \epsilon_V(p_K) \cdot \epsilon_T(p_K, E_{cm})$. Here $\epsilon_V(p_K)$ denotes the probability of detecting both pions in the fiducial volume of the detector and finding the vertex by the above criteria. Integrated over all angles, ϵ_V will only depend on the momentum p_K and can, in principle, be well determined. In practice, our Monte Carlo programs do not simulate losses due to tracking inefficiencies and non-Gaussian tails in the mass distribution and the angular resolution. We estimate these losses to amount to about 15%, and have globally corrected for them through the factor ϵ_0. The third term $\epsilon_T(p_K, E_{cm})$ describes the probability for an event with an observable K_S decay to trigger and to satisfy our event selection criteria for a hadronic final state. This quantity depends on the multiplicity and dynamics of final states containing neutral kaons. Its accuracy is limited by our lack of knowledge about the production mecha-

Table 1
Measurement of the total $K^0-\bar{K}^0$ production as a function of the center-of-mass energy

c m. energy E_{cm} (GeV)	mean c.m. energy (GeV)	integrated luminosity (nb^{-1})	observed number of K_S decays	inclusive K_S cross section σ_{K_S} (nb)	$R_K = \dfrac{2\sigma_{K_S}}{\sigma_{\mu\mu}}$
3.4 −3.8	3.65	175	68±10	3.0±0 7	0 92±0.20
3.8 −4.0	3 95	370	160±16	4.2±0.6	1.50±0.21
4.028	4.028	1260	1087±43	8.3±0 5	3 10±0 18
4 08−4.18	4 12	330	173±18	5.6±0 8	2.18±0.31
4.18−4 39	4.28	460	214±20	4.5±0 6	1.90±0 27
4.415	4.415	1600	1123±45	6.3±0.4	2 80±0.18
4.44−4.8	4.59	375	158±16	4 3±0.7	2.10±0.34
4.8 −4.5	5.16	200	64±11	2.8±0.5	1.72±0 29
5.4 −6.1	5.90	1820	532±33	2.7±0.3	2 20±0 26
6.1 −6.3	6.18	1640	482±31	2 6±0.3	2 28±0.24
6.3 −6.8	6.54	1940	555±32	2 5±0.2	2.44±0 20
6.8 −7.3	7.1	6100	1308+50	1.8±0.1	2 10±0.14
7.3 −7.6	7.4	4480	1024±42	1.9±0 1	2 40±0.16

nism. In the Monte Carlo simulation used to determine ϵ_T, the detected kaon momentum spectrum, the average multiplicity and momenta of all detected charged particles have been adjusted to agreee with the data for the various c.m. energies under study. These parameters are found to be the most critical in the determination of the trigger efficiency [2]. They vary smoothly and slowly as a function of c.m. energy. Likewise, ϵ_T is a smooth function: it increases for increasing energy because the multiplicity of the final state rises, ϵ_T decreases with increasing kaon momentum. The model calculations include particle correlations described by the formation of jets [7].

The overall uncertainty in the determination of the efficiency ϵ is mainly due to deficiencies'in these model calculations and is estimated to amount to 10−15%. In particular, the number of kaons in low multiplicity events is not well known. This will specifically increase the uncertainties for high momentum kaons.

The K_S detection efficiencies have been studied in detail at 4 GeV and 7.4 GeV. For any other energy E_{cm}, the value $\epsilon(p_K, E_{cm})$ is derived by linear interpolation. The efficiency ϵ is essentially zero below 100 MeV/c, rises smoothly to a maximum of roughly 25% at 1 GeV/c momentum and decreases slowly at higher momenta. A cut at 200 MeV/c momentum has been introduced to avoid large uncertainties. This loss at low momentum has been estimated from an extrapolation of the observed

spectrum to zero momentum. The correction amounts to 4% at 4 GeV and decreases to 2% above 7 GeV. The known branching ratio has been used to correct for the unobserved decay mode $K_S \to \pi^0\pi^0$.

From the calculated detection efficiency, the observed K_S momentum spectrum, and the luminosity corresponding to each c.m. energy interval, we have evaluated inclusive K_S cross sections. The results are given in table 1. Large angle Bhabha scattering events have been used to normalize the data. The procedure for the evaluation of the integrated luminosity is discussed in ref. [2]. Radiative corrections have only been applied to remove the tail of $\psi(3684)$ resonance. The quoted errors include statistical errors added in quadrature to systematic uncertainties. These systematic errors are estimates of the point-to-point fluctuations which arise from errors in background subtraction, normalization, and corrections for losses in the vertex selection and cuts in mass and momentum. The errors are consistent with the reproducibility of the results under various other selection criteria. Not included is the 10−15% uncertainty in absolute normalization. Furthermore, a smooth variation of as much as 15% from the lowest of the highest energy could arise from systematic errors in the energy dependence of the overall detection efficiency. These errors are largely the same as for total hadron production [2].
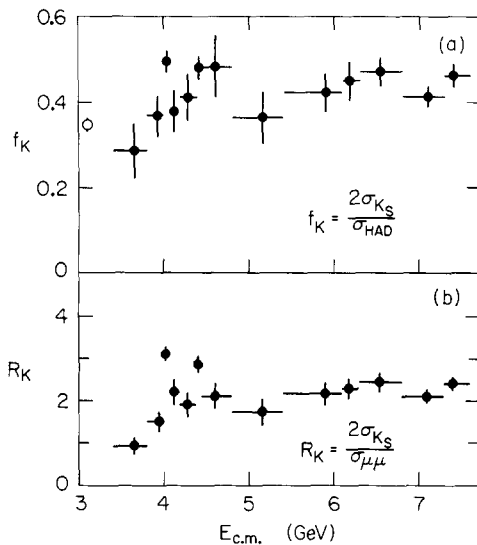
In fig. 2 we compare the inclusive kaon production

Fig 2. Inclusive production of neutral kaons as a function of c m energy (a) ratio of kaon to total hadron production, (b) ratio of kaon to muon pair production. The errors include systematic uncertainties. The data point of 3.1 GeV refers to the $\psi(3095)$ resonance.

Fig. 3. Inclusive spectra for neutral K mesons as a function of $x = 2E_K/E_{c.m.}$ at various c.m. energies, where E_K denotes the kaon energy and $s = E_{c.m.}^2$ and σ refers to twice the K_S cross section. The errors are statistical only.

to the total hadron production and to muon pair production. We assume an equal number of K_S and K_L and define $f_K = 2\sigma_{K_S}/\sigma_{HAD}$ and $R_K = 2\sigma_{K_S}/\sigma_{\mu\mu}$. Above 4 GeV, where most of the data have been recorded, there is roughly one K_S for every four hadronic final states. Except for a 20% excess at 4.028 GeV and 4.415 GeV, the fraction f_K shows rather little variation as a function of c.m. energy. Above 4 GeV, the ratio R_K appears roughly constant with a value of 2.2, except at 4.028 GeV and 4.415 GeV, where we observe significant deviations from this average. Below 3.8 GeV, R_K is smaller by about a factor of two, though our statistics are very limited.

A difference between the data recorded at the center of the 4.028 GeV and 4.415 GeV peaks and the data in the high energy plateau can also be found in the inclusive momentum distributions. In fig. 3 the data are presented in terms of the scaling variable $x = 2E_K/E_{cm}$, where E_K denotes the kaon energy. Again, the measured K_S rates have been doubled to obtain the neutral kaon cross sections. The quantity $s\, d\sigma/dx$, where s equals E_{cm}^2, is expected to scale for large s, where R_K is constant. For $x > 0.6$ the spectra agree for all c.m. energies, though the errors are substantial. Below $x = 0.5$, the 4.028 GeV and 4.415 GeV data are
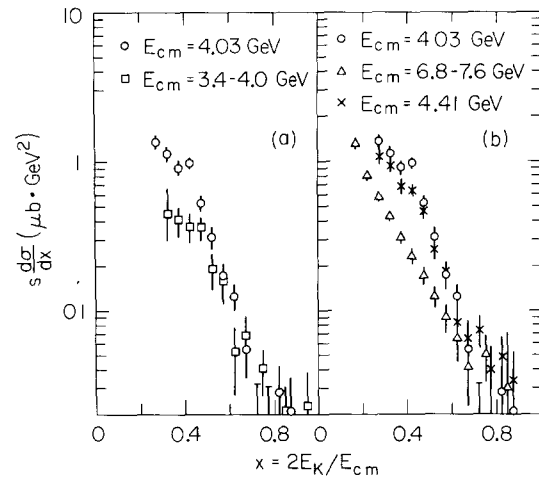
strongly enhanced compared to the data sampled below 4 GeV and above 6 GeV. A similar behavior has been found for charged pions and kaons.[3,8,9].

In summary, the inclusive neutral kaon production has roughly the same energy dependence as the total hadron cross section. The ratio of K_S to muon pair production shows a significant rise just below 4 GeV c.m. energy and reaches a plateau about 5 GeV. At 4.028 GeV and 4.415 GeV where the total hadron production peaks, neutral kaon yields are also substantially enhanced. The observation of similar enhancements in the number of kaons per hadronic event supports the hypothesis that the rise and the structure in hadron production is due to the threshold for associated production of charmed mesons that decay preferentially to final states of non-zero strangeness [1]. The kaon excess occurs for $x < 0.6$. This fact further supports the interpretation of the kaon excess as arising from the decays of charmed particles, as confirmed by measurements of exclusive decay modes of the D^0 and D^+ mesons [10, 11, 12].

The results presented here are in general agreement with measurements at DESY on inclusive $K^\pm$ production [13] and K_S production [14], below 5 GeV. Neither DESY group, however, has observed the enhanced kaon yield at the 4.415 GeV structure.

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