K^{*0} and K_S^0 Meson Production in e^+e^- Annihilations at 29 GeV

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(Received 24 September 1984)

The inclusive production cross sections and transverse momentum distributions of K^{*0} and K_S^0 mesons in e^+e^- annihilation at a center-of-mass energy of 29 GeV have been measured by means of the time projection chamber detector in the PEP-4 experiment. The mean multiplicities are found to be $0.49 \pm 0.04(\text{stat.}) \pm 0.07(\text{syst.})$ $(K^{*0}+\bar{K}^{*0})$ and $1.22 \pm 0.03(\text{stat.}) \pm 0.15(\text{syst.})$ $(K^0+\bar{K}^0)$ per event.

PACS numbers: 13.65.+i, 14.40.Aq, 14.40.Ev

The study of resonance production in high-energy e^+e^- annihilations has a twofold significance. First, since reasonable production is expected to be less dominated by decays of heavy particles as compared to stable hadrons, its dynamics is more directly related to the original momentum and quantum-number flows in an event. Second, this type of data serves further to constrain various quark fragmentation models with a number of phenomenological parameters, among which is the production ratio of resonances and stable particles. In this Letter we report measurements of K^{*0} and K_S^0 production, based on data taken by means of the PEP-4 time projection chamber (TPC) facility at the PEP storage ring at the Stanford Linear Accelerator Center. The TPC has a typical momentum resolution of $(\delta p/p)^2=(0.06)^2+(0.035p)^2$ (p in GeV/c), and identifies charged particles by dE/dx measurement with a typical resolution of 3.7%.[1] The event selection criteria have been described elsewhere.[2] The data sample consists of 29 100 events, corresponding to an integrated luminosity of 77 pb^{-1} at a center-of-mass energy of 29 GeV.

The K^{*0} and $\bar{K}^{*0}$ (hereafter, we write only the particle state to indicate both particle and antiparticle states) are reconstructed in the decay mode $K^{*0}\to K^+\pi^-$, where both K^+ and π^- are identified by the TPC. The charged track selection and particle identification follow the procedure described previously.[3] In this analysis a charged track is counted as a K^+ or π^- if its particle weight $W(K)$ or $W(\pi)$ exceeds 0.5. This results in K (π) sample purities of 55%–90% (85%–95%) and efficiencies of 50%–70% (50%–70%), depending on the momentum. Figures 1(a) and 1(b) show the $K\pi$ invariant mass spectra in the range $0.0618 < x < 0.800$ $(x=2E/\sqrt{s})$ for opposite-sign and like-sign combinations, respectively. A prominent peak is seen for the opposite-sign combinations in the K^* region $(M_{K\pi}\simeq 0.89$ GeV), but is absent for the like-sign combinations. The spectrum is well fitted with a smooth background plus a P-wave Breit-Wigner resonance shape as shown by solid curves in Fig. 1(a). We find 2750 ± 104 entries, $M=900.5\pm 3.6$ MeV,[4] and $\Gamma=88.1\pm 9.5$ MeV (full width at half maximum) for the peak, consistent with the K^{*0} intrinsic width (50.2 MeV) folded in with the detector resolution. Effects of $\rho^0\to\pi^+\pi^-$, $\omega\to\pi^+\pi^-\pi^0$, $K_S^0\to\pi^+\pi^-$, $D\to K^-\pi^+X$ (with the $K\pi$ pair not coming from K^{*0}), and photon conversion pairs, whose products were taken to be a $K\pi$ pair, are estimated with a Monte Carlo calculation.[5] They form only a small

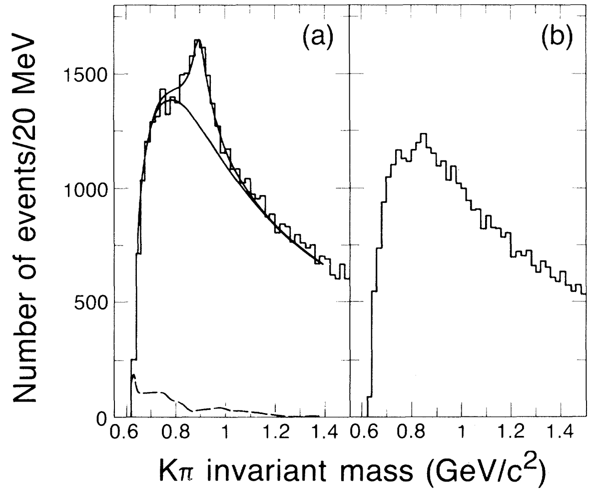

FIG. 1. (a) Sum of $K^+\pi^-$ and $K^-\pi^+$ invariant mass spectra in the energy range $0.0618 < x < 0.8$, where $x = 2E/\sqrt{s}$. The smooth curves are described in the text. (b) Sum of $K^-\pi^-$ and $K^+\pi^+$ invariant mass spectra in the same range.

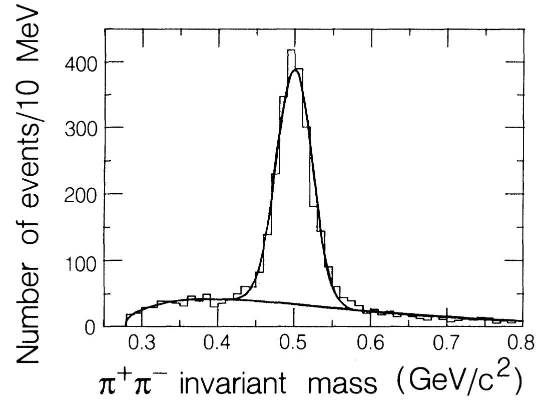

FIG. 2. The $\pi^+\pi^-$ invariant mass spectrum of K_S^0 candidates in the range $0.05 < x < 0.6$. The fitted curves are described in the text.

structure in the K^* region as shown by the dashed curve in Fig. 1(a), and are comparable with statistical fluctuations of the overall background level. This justifies the use of a single smooth background in our analysis.

Neutral K-meson production is studied by reconstructing the decay $K_S^0 \rightarrow \pi^+\pi^-$, whose decay vertex is separated from the event vertex. Combinations are formed for opposite-sign pairs of tracks, each of which satisfies the following conditions: (1) momentum p exceeds 0.15 GeV/c; (2) estimated error in the momentum measurement fulfills $\delta p/p < 0.4$ or $\delta p/p^2 < 0.3$; (3) χ^2 (d.o.f. = 1) for a $\pi^\pm$ hypothesis calculated from the momentum and dE/dx is smaller than 7; and (4) distance of closest approach to the event vertex is larger than $(0.04 + 0.02/p^2)^{1/2}$ cm. A track pair is accepted as a K_S^0 candidate if (1) the minimum three-dimensional distance between the tracks is smaller than 0.5 cm; (2) the momentum vector of the pair points within 14° to the event vertex; and (3) the flight path from the event vertex is longer than 1.5 cm. Pairs whose tracks are consistent with photon conversions are rejected. Figure 2 shows the $\pi^+\pi^-$ effective mass spectra in the range $0.05 < x < 0.60$. Fitting the spectrum with a smooth background plus a Gaussian line shape (indicated by the solid smooth curve in Fig. 2) results in 2076 ± 52 entries, $M = 499.7 \pm 0.6$ MeV,[4] and $\sigma(\mathrm{rms}) = 23.3 \pm 0.5$ MeV for the peak, consistent with our detector resolution.

The production rates of K^{*0} and K^0 are obtained as functions of x and p_T^2 (p_T is the transverse momentum relative to the thrust axis) by use of the fitted $K\pi$ and $\pi\pi$ mass spectra in various energy and p_T^2 intervals, with the assumption that half of K^0 would turn out to be K_S^0. Background shapes are inferred from a Monte Carlo calculation.[5] As a result of the large Q value (0.288 GeV/c) of its decay, the acceptance for K^{*0} is nearly constant (15%–20%) over a wide momentum range. The K_S^0 acceptance varies between 6% and 20%, with a momentum dependence dominated by the cut on the flight path.

The K^{*0} and K^0 rates, corrected for acceptance and effects of initial-state radiation,[6] are stable against changes in track-selection and particle-identification cuts. However, our Monte Carlo study shows that the shape and the magnitude of the $K\pi$ background in the K^{*0} analysis are sensitive to uncertainties in the multiplicities and momentum distributions of $\pi^\pm$ and $K^\pm$ to be assumed for the annihilation events. Therefore, we assign systematic errors of typically 15% for K^{*0} rates, dominated by uncertainties in the background subtraction. The results are summarized in Fig. 3, Fig. 4, and Table I. We observe an average of $0.49 \pm 0.04 \pm 0.07$ ($K^{*0} + \bar{K}^{*0}$) per event in the range $0.0618 < x < 0.8$, and $1.07 \pm 0.03 \pm 0.13$ ($K^0 + \bar{K}^0$) in $0.05 < x < 0.6$. The first error quoted is statistical and the second is systematic. The Lund Monte Carlo program[5] predicts that 99.7% of K^{*0} and 87.6% of K^0 are contained within these energy ranges; this infers that the total multiplicity of K^{*0} (K^0)[7,8] is $0.49 \pm 0.04 \pm 0.07$ ($1.22 \pm 0.03 \pm 0.15$). Our K^0 multiplicity is consistent with the results from experiments at PETRA[9] and with the $K^\pm$ rate reported in Ref. 2.

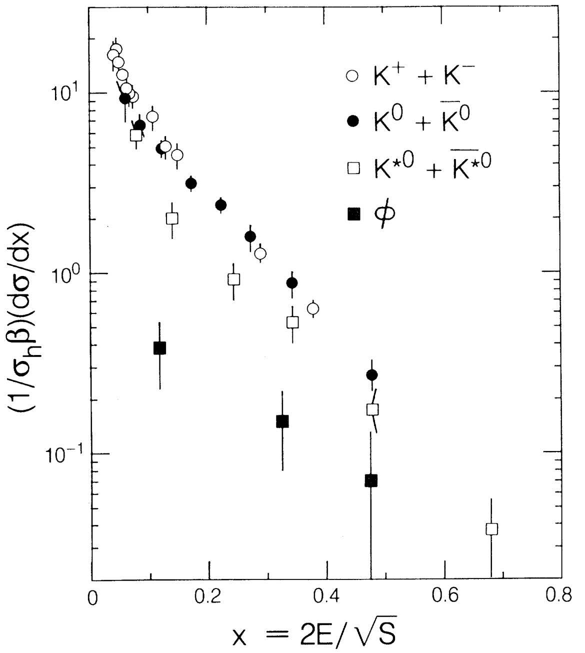

FIG. 3. Differential cross sections vs $x = 2E/\sqrt{s}$, for K^0, $K^{\pm}$ (taken from Ref. 2), K^{*0}, and ϕ (taken from Ref. 3).

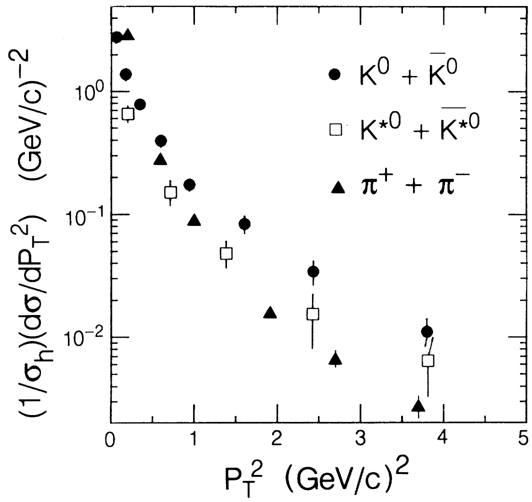

FIG. 4. Production rates of K^0, K^{*0}, and $\pi^{\pm}$ (scaled by a factor of $\frac{1}{8}$) as functions of p_T^2 relative to the thrust axis.

The measured average p_T^2 relative to the thrust axis is $0.57 \pm 0.07 \pm 0.03$ $(\mathrm{GeV}/c)^2$ for K^{*0} in $0.0618 < x < 0.8$, and $0.51 \pm 0.10 \pm 0.18$ $(\mathrm{GeV}/c)^2$ for K^0 in $0.05 < x < 0.6$. Predictions of the Lund model in the same ranges are 0.59 $(\mathrm{GeV}/c)^2$ for K^{*0} and 0.49 $(\mathrm{GeV}/c)^2$ for K^0, both consistent with our measurements. For comparison, the average p_T^2 for $\pi^{\pm}$ measured by this experiment is $0.30 \pm 0.01 \pm 0.02$ $(\mathrm{GeV}/c)^2$ in $x > 0.01$. The p_T^2 distributions, including $\pi^{\pm}$ data, are shown in Fig. 4.

These results, together with our previously measured production rates of $K^{\pm}$ (Ref. 2), permit us to estimate the ratio $V/(V+P)$, the fraction of vector meson production for strange mesons.[10] Using the measured D^*/D production ratio,[11] the assumption that 13% of primary charm would turn into F or F^* mesons, and the measured charm/bottom decay branching ratios,[12] we estimate the multiplicity of $K^{\pm}$ (K^0) from charm/bottom decays to be 0.41 ± 0.06 (0.34 ± 0.07). After subtraction of these contributions and effects of ϕ decays, the number of $K^{\pm}$ (K^0) which are of non-charm/bottom and non-ϕ origin is 0.86 ± 0.15 (0.82 ± 0.16). Similarly,[12] the K^{*0} multiplicity from noncharm and nonbottom origin is estimated to be 0.39 ± 0.11. Assuming that K^{*0} and $K^{*\pm}$ are produced at an equal rate, we obtain $V/(V+P) = 0.47 \pm 0.11 \pm 0.09$, where the first error is experimental, and the second error comes from ambiguities in charm/bottom decay branching ratios. This is in fair agreement with the values reported by Brandelik *et al.*[13] and Bartel *et al.*[8]

Using the ratio of our measured production rates for ϕ (Ref. 3) and K^{*0}, we can estimate the

TABLE I. The inclusive K^{*0} and K^0 production rates normalized to the total annihilation cross section into hadrons. Here $x = 2E/\sqrt{s}$ and β is the particle velocity. The first error quoted is statistical; the second is systematic.

x	$\langle x \rangle$	$(1/\sigma_h\beta)\,d\sigma/dx$
	$e^+e^- \to K^{*0},\overline{K}^{*0} + X$	
0.0618–0.10	0.079	$5.80 \pm 0.66 \pm 0.63$
0.10–0.20	0.14	$2.01 \pm 0.28 \pm 0.35$
0.20–0.30	0.25	$0.92 \pm 0.16 \pm 0.14$
0.30–0.40	0.35	$0.53 \pm 0.10 \pm 0.06$
0.40–0.60	0.48	$0.18 \pm 0.04 \pm 0.02$
0.60–0.80	0.67	$0.038 \pm 0.016 \pm 0.007$
	$e^+e^- \to K^0,\overline{K}^0 + X$	
0.05–0.075	0.062	$9.27 \pm 0.91 \pm 2.19$
0.075–0.10	0.086	$6.61 \pm 0.55 \pm 0.80$
0.10–0.15	0.12	$4.91 \pm 0.29 \pm 0.42$
0.15–0.20	0.17	$3.15 \pm 0.17 \pm 0.24$
0.20–0.25	0.22	$2.40 \pm 0.14 \pm 0.19$
0.25–0.30	0.27	$1.57 \pm 0.21 \pm 0.15$
0.30–0.40	0.34	$0.87 \pm 0.10 \pm 0.10$
0.40–0.60	0.68	$0.27 \pm 0.04 \pm 0.03$

suppression factor of $s\bar{s}$-quark pair production from the vacuum—the s/u ratio. From $2N(\phi)/N(K^{*0})$, with corrections for charm/bottom decays and primary strange quarks, we obtain $s/u = 0.37 \pm 0.15 \pm 0.08$. Also, by comparing K^{*0} and the TASSO collaboration ρ^0 rates,[13] we get $s/u = 0.32 \pm 0.09 \pm 0.05$ from $N(K^{*0})/2N(\rho^0)$. We observe that both the ϕ/K^{*0} and K^{*0}/ρ^0 production ratios appear to be governed by a single parameter s/u, as assumed in many quark fragmentation models.

We acknowledge the efforts of the PEP staff, and the engineers, programmers, and technicians of the collaborating institutions who made this work possible. This work was supported by the U. S. Department of Energy under Contracts No. DE-AC03-76SF00098, No. DE-AM03-76SF00034, and No. DE-AC02-76ER03330, the National Science Foundation, and the Joint Japan–U.S. Collaboration in High Energy Physics.

[1]H. Aihara *et al.* (TPC Collaboration), IEEE Trans. Nucl. Sci. **30**, 63, 67, 76, 117, 153 (1983).

[2]H. Aihara *et al.*, Phys. Rev. Lett. **52**, 577 (1984).

[3]H. Aihara *et al.*, Phys. Rev. Lett. **52**, 2201 (1984).

[4]The error is statistical only. The systematic error in the mass due to uncertainty in the magnetic field is estimated to be 0.5%.

[5]We use the Lund model [B. Andersson *et al.*, Z. Phys. C **20**, 317 (1983)], in conjunction with our detector simulation program. See Ref. 3.

[6]F. A. Berends and R. Kleiss, Nucl. Phys. **B178**, 141 (1981).

[7]H. Schellman *et al.* (MARK II Collaboration), SLAC Report No. SLAC-PUB-3448 (to be published), have recently reported consistent results.

[8]W. Bartel *et al.* (JADE Collaboration), Phys. Lett. **145B**, 441 (1984), report $0.87 \pm 0.16(\text{stat.}) \pm 0.08(\text{syst.})$ $K^{*\pm}$/event, larger than our measured K^{*0} multiplicity by 2 standard deviations. Within the Lund model, they obtain $V/(V+P) = 0.70 \pm 0.15 \pm 0.11$. They also report $0.98 \pm 0.09 \pm 0.15$ ρ^0/event.

[9]R. Brandelik *et al.* (TASSO Collaboration), Phys. Lett. **94B**, 91 (1981); Ch. Berger *et al.* (PLUTO Collaboration), Phys. Lett. **104B**, 79 (1981); W. Bartel *et al.* (JADE Collaboration), Z. Phys. C **20**, 187 (1983).

[10]In arguments in this and the next paragraphs we implicitly assume that the production of higher-spin mesons ($J^P = 1^+, 2^+, \ldots$) and baryon resonances can be neglected.

[11]J. M. Yelton *et al.* (MARK II Collaboration), Phys. Rev. Lett. **49**, 430 (1982); Ahlen *et al.* (HRS Collaboration), Phys. Rev. Lett. **51**, 1147 (1983). The ambiguity in the $D/D^*/F/F^*$ ratio affects our values of $V/(V+P)$ and s/u by less than 3%.

[12]R. H. Schindler *et al.* (MARK II Collaboration), Phys. Rev. D **24**, 78 (1981); J. Green *et al.* (CLEO Collaboration), Phys. Rev. Lett. **51**, 347 (1983). We also assume D and F decay branching ratios as follows:

$$B(D \to K^*X) = B(D \to \rho^0 X) = B(F \to K^*X) = (10 \pm 10)\%,$$

$$B(F \to K^0 \text{ or } \bar{K}^0 X) = B(F \to K^{\pm} X) = (50 \pm 25)\%.$$

Note that a K-$\bar{K}$ pair is often expected as decay products of F.

[13]R. Brandelik *et al.* (TASSO Collaboration), Phys. Lett. **117B**, 135 (1982), report $0.22 \pm 0.02(\text{stat.}) \pm 0.05(\text{syst.})$ ρ^0/event in $0.2 < x < 0.7$. Within a Field-Feynman fragmentation model, they obtain $V/(V+P) = 0.58 \pm 0.08 \pm 0.15$. For comparison with our measured K^{*0} rate, we use the Lund model to extrapolate to the entire x range and estimate the total ρ^0 multiplicity to be $0.72 \pm 0.07 \pm 0.16$ per event.