# INCLUSIVE $K^0$ PRODUCTION IN $e^+e^-$ ANNIHILATION FOR $9.3 < \sqrt{s} < 31.6$ GeV

PLUTO Collaboration

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Results on inclusive $K^0_S$ production in $e^+e^-$ annihilation at mean center-of-mass energies of 9.4, 12.0 and 30 GeV are presented. The ratio $R(K^0) = 2\sigma(K^0_S)/\sigma_{\mu\mu}$ rises from $3.10 \pm 0.75$ at $\sqrt{s} = 9.4$ GeV to $5.6 \pm 1.2$ at $\sqrt{s} = 30$ GeV, corresponding to an approximately constant $K^0$/charged-particle ratio of $0.12 \pm 0.02$. A similar ratio for $K^0$/charged particle is observed for direct hadronic decays of the $\Upsilon$.

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In high-energy lepton–lepton, lepton–hadron, or hadron–hadron collisions the study of the properties of quark or gluon produced jets is of considerable current interest [1] [‡1]. While studies of jet evolution are often carried out without particle identification, a knowledge of the production characteristics of specific particle types, such as baryons or strange particles is of importance. In this paper we present data on inclusive $K^0_S$ distributions produced by $e^+e^-$ annihilations at center-of-mass energies, $\sqrt{s}$ = 9.4, 12.0 and ~30 GeV. Measurements on the $\Upsilon$ resonance may be used to extract information about hadronisation in gluon jets.

The data were obtained with the PLUTO detector running at DORIS for the 9.4 GeV data, and at PETRA for the 12.0 and 27.6–31.6 GeV data. Descriptions of the detector, trigger and selection conditions for hadronic events have been given in earlier publications [2,3]. For this investigation an additional off-line event selection required the total charged particle energy to be greater than $\sqrt{s}/4$ in order to reduce beam–gas and two-photon contributions. The data corresponds to integrated luminosities of 350, 100 and 2980 $nb^{-1}$ at 9.4, 12.0 and 27.6–31.6 GeV, respectively.

The $e^+$ and $e^-$ beams are incident along the axis ($z$-axis) of the inner charged particle detector, which consists of 13 concentric cylindrical proportional wire chambers. There is an axial magnetic field of 1.65 T. $K^0_S$ candidates are found by examining all pairs of oppositely charged tracks for $V^0$ candidates satisfying the following conditions:

(a) Each track must hit a minimum of 6 chambers in the inner detector. The first hits on the two tracks considered must not differ by more than one chamber.

(b) $d^+d^- \geqslant 25\ mm^2$, $d$ is the minimum radial distance of the extrapolated track from the beam line as projected in the $x$–$y$ plane, defined as $d = s - r$, where $r$ is the radius of curvature of the projected track and $s$ is the distance of the center of curvature from the beam line.

(c) At the crossing point of the tracks in the $x$–$y$ plane, the separation between the tracks in the $z$ direction must be less than 40 mm.

(d) The line of flight of the candidate $V^0$, as projected in the $x$–$y$ plane, must pass within 7.5 mm of the beam line.

[‡1] For a recent experimental review, see ref. [13].

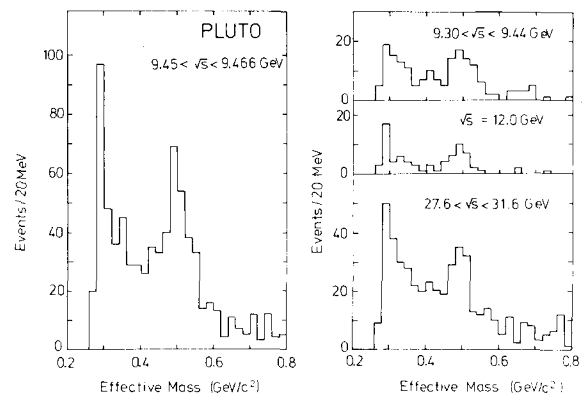


Fig. 1. The observed effective mass distributions for accepted $V^0$ candidates, assuming both tracks to be pions, for each of the energy regions studied.

(e) The radial distance of the $V^0$ vertex from the interaction point is required to lie between 10 and and 200 mm for the 9.4 GeV data, and between 20 and 200 mm for the 12 and 30 GeV data.

For pairs of tracks satisfying the above criteria the effective mass is calculated assuming both particles to be pions. The resulting effective mass distributions are shown in fig. 1 for each of the four energy regions studied. Clearly separated peaks corresponding to $K^0_S \to \pi^+\pi^-$ and to converted photons are observed. The $K^0$ peaks have a resolution of $\sigma$ = 20–30 MeV with a signal to background ratio of ~2 : 1 at 9.4 GeV and ~1 : 1 at 30 GeV. The observed $K^0_S$ lifetime has been checked to be consistent with the established value [4].

Corrections for the applied cuts and track reconstruction inefficiencies have been determined using a Monte Carlo simulation. Hadronic events were generated using the model of Ali et al. [5], which uses a model of quark and gluon fragmentation based on the ideas of Field and Feynman [6]. The generated events were then passed through a simulation program for the PLUTO detector, and finally processed by the same chain of programs as used to process the data. The resulting detection efficiency for $K^0_S \to \pi^+\pi^-$ at $\sqrt{s} \approx 30$ GeV reaches a maximum of 16% for a $K^0$ momentum of 1.5 GeV/$c$ and falls to 5% for momenta of 0.3 and 5 GeV/$c$. For the lower energy data the detection efficiency is somewhat higher, due to the higher track recognition efficiency which results from the lower charged-particle multiplicity.

In presenting the data we have also corrected for

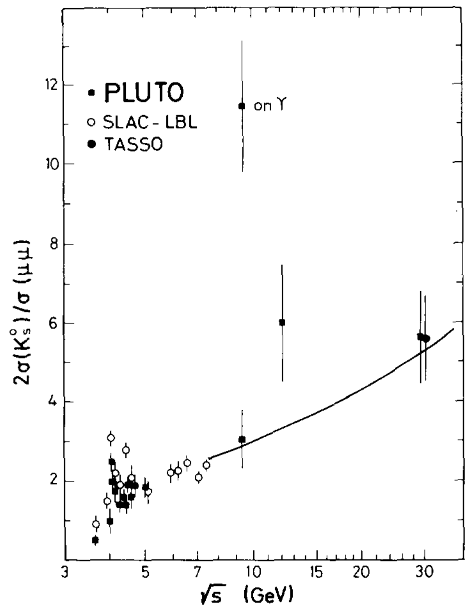


Fig. 2. $R(K^0) = 2\sigma(e^+e^- \to K_S^0 + X)/\sigma(e^+e^- \to \mu^+\mu^-)$ as a function of $\sqrt{s}$. The curve is proportional to the mean charged multiplicity, $\langle n_{ch}\rangle$. The "on Υ" point is the average value of $R(K^0)$ measured for $9.45 \leqslant \sqrt{s} \leqslant 9.466$ GeV.

the known $K_S^0$ branching ratios [4]. Our results cover the $K^0$ momentum range $0.3 \leqslant p_K \leqslant 4.5$ GeV/$c$ and are given in terms of $2\sigma(K_S^0) = 2\sigma(e^+e^- \to K_S^0 + X)$ or equivalently $\sigma(K^0 + \bar{K}^0)$. Since our observed momentum distributions are consistent with the Monte Carlo model calculations, we use these calculations to correct for the unobserved $K^0$ momentum ranges, when determining the inclusive cross sections for $e^+e^- \to K^0 + X$. We have used the Lund Monte Carlo model [7] to determine the corrections for Υ events; for the continuum, the two Monte Carlos give consistent results for the momentum distributions. The corrections are ~10–15%.

Fig. 2 shows the energy dependence of the ratio

$$R(K^0) = 2\sigma(e^+e^- \to K_S^0 + X)/\sigma(e^+e^- \to \mu^+\mu^-) .$$

In this figure only, systematic errors (~12%) arising mainly from uncertainties in the efficiency determination are also included. Also shown are a result from the TASSO experiment [8] and lower energy data from PLUTO and MARK J [9]. The upper and lower points at ~9.4 GeV correspond to data taken on the Υ resonance ($9.45 \leqslant \sqrt{s} \leqslant 9.466$ GeV) and data from the nearby continuum ($9.30 \leqslant \sqrt{s} \leqslant 9.44$ GeV), respectively. The increase of the $K^0$ cross section at the Υ is similar to the increase of the total hadronic cross section, as indicated by the similar ratios of $K^0$/hadronic event for Υ-direct and off-Υ (see table 1). The curve is proportional to the mean charged multiplicity $\langle n_{ch}\rangle$ [10] and shows $R(K^0)$ and $\langle n_{ch}\rangle$ to have a similar energy dependence between 7 and 30 GeV. Since, for the continuum,

$$R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$$

is constant in this range [11], the implication is that the ratio $K^0$/charged particle and therefore the $K/\pi$ ratio is approximately constant. We find $\langle K^0\rangle/\langle n_{ch}\rangle = 0.106 \pm 0.023$ at $\sqrt{s} = 9.4$ GeV (off-Υ) and $=0.138 \pm 0.028$ at $\langle\sqrt{s}\rangle = 30$ GeV where $\langle K^0\rangle$ is the mean number of $K^0 + \bar{K}^0$ per hadronic event. The fragmentation model [6] predicts the approximate constancy of the $K^0$/charged-particle ratio over this energy range. Further statistics at 12 GeV would be necessary to determine whether the apparent high $K^0$ rate observed at this energy is a real effect. Table 1 summarizes our results on inclusive $K^0$ rates.

In fig. 3 the $K^0$ momentum spectrum is shown in

Table 1
Inclusive $K^0$ rates in the annihilation process $e^+e^- \to K^0 + X$. [Errors are statistical only, except for $R(K^0)$.]

| $\sqrt{s}$ (GeV) | $R(K^0) = \dfrac{2\sigma(e^+e^- \to K_S^0 + X)}{\sigma(e^+e^- \to \mu^+\mu^-)}$ | $K^0$/hadronic event | $\langle n_{ch}\rangle$ a) | $K^0$/charged particle |
|---|---|---|---|---|
| 9.30 – 9.44 (off Υ) | 3.08 ± 0.75 | 0.73 ± 0.16 | 6.9 ± 0.1 | 0.106 ± 0.023 |
| 9.45 – 9.466 (Υ-direct) | – | 0.97 ± 0.22 | 8.2 ± 0.1 b) | 0.118 ± 0.027 |
| 12.0 | 6.0 ± 1.5 | 1.5 ± 0.4 | 7.4 ± 0.2 | 0.20 ± 0.05 |
| 27.6 – 31.6 | 5.6 ± 1.2 | 1.46 ± 0.30 | 10.6 ± 0.1 | 0.138 ± 0.028 |

a) Ref. [10]. b) Ref. [16].

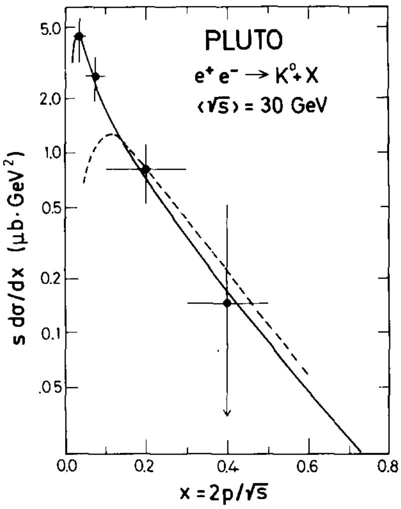


Fig. 3. $sd\sigma/dx$ for the data in the energy range $27.6 < \sqrt{s} < 31.6$ GeV. The solid curve indicates the model prediction (see text). The dashed curve is the prediction for $\sqrt{s} = 9.4$ for comparison.

terms of $x = 2p/\sqrt{s}$ for data in the energy range $27.6 < \sqrt{s} < 31.6$ GeV. The solid curve represents the cross section resulting from the Field and Feynman type of quark fragmentation algorithm as used in the Lund Monte Carlo [7]. However, the "standard" probability for picking up an $s\bar{s}$ quark pair from the vacuum (as opposed to $u\bar{u}$ or $d\bar{d}$) of 0.2 [6] predicts an inclusive $K^0$ cross section that is higher ($R_K \sim 7.5$) than the value observed at 30 GeV ($R = 5.6 \pm 1.2$). A probability of 0.14, as also suggested by electroproduction data [12], appears to represent the data better. We therefore use the value 0.14 in all our fragmentation model calculations in this letter. Our data for $\langle\sqrt{s}\rangle \sim 30$ GeV is also in good agreement with similar differential distributions from the TASSO experiment [8] as shown in ref. [13].

In fig. 4a we show the $K^0$ $x$-distribution for $\langle\sqrt{s}\rangle = 9.4$ GeV below the $\Upsilon$ resonance. The curve indicates the quark fragmentation model prediction [7], which is again in good agreement with the data. The same curve is also shown as a dashed line in fig. 3 to indicate the approximate scaling of the data for $x > 0.1$.

Fig. 4b shows the $K^0$ $x$-distribution for direct hadronic decays of the $\Upsilon$. The data is obtained by a background subtraction in the $\Upsilon$ resonance region ($9.45 \leqslant \sqrt{s} \leqslant 9.466$ GeV) which eliminates the contributions of the continuum and vacuum polarisation

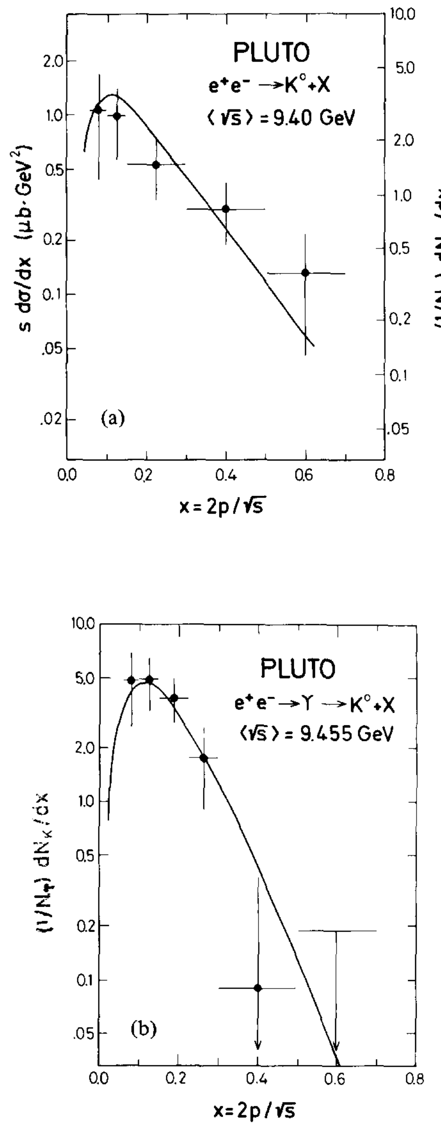


Fig. 4. (a) $sd\sigma/dx$ for the continuum at $\sqrt{s} = 9.4$ GeV. Also given is the yield per hadronic event $N_h^{-1}(dN_K/dx)$. The curve indicates the model prediction. (b) Yield per $\Upsilon$-event, $N_\Upsilon^{-1} \times (dN_K/dx)$ for the $\Upsilon$-direct decays after background subtraction. The curve represents the prediction of a $\Upsilon \to$ three-gluon decay model (see text).

effects [14]. The size of the vacuum polarisation effects has been determined from a comparison of the $e^+e^- \to \mu^+\mu^-$ yields for the data on the $\Upsilon$ resonance and the nearby continuum. The solid curve is the prediction of the $\Upsilon \to$ three-gluon decay model followed by gluon fragmentation [7]. Because one of the gluons will mostly have a very low energy, in practice the model becomes essentially a two-gluon model. The agreement of the model with the data is good.

Comparison of figs. 4a and 4b gives some indication that the $K^0$ momentum distribution from $\Upsilon$-direct decays falls off faster with increasing momentum than for $K^0$ produced from $e^+e^- \to q\bar{q}$. The shapes of the two distributions differ by about $2\sigma$. Qualitatively similar behavior is also observed for inclusive distributions for charged particles [15], where using the parameterisation $dN/dx \sim \exp(-Bx)$ for $x > 0.1$, $B = 7.8 \pm 0.2$ for continuum events and $10.9 \pm 0.3$ for $\Upsilon$-direct events. These slopes are close to the dependence of the fragmentation curves of figs. 4a and 4b.

Finally we compare the inclusive $K^0$ yield at 9.4 GeV on and off the $\Upsilon$ resonance. The mean number of $K^0$ per hadronic event is $0.73 \pm 0.16$ for the continuum and $0.97 \pm 0.22$ for $\Upsilon$-direct events. Because of the higher mean charged multiplicity [16] for $\Upsilon$-direct events the $K^0$ per charged particle ratio is similar for $\Upsilon$-direct decays and continuum (see table 1) despite the very different processes involved, see also ref. [17].

To summarise, the inclusive production of $K^0$ in $e^+e^-$ annihilation is satisfactorily described by the fragmentation models for the energy range studied, $9.4 < \sqrt{s} < 30$ GeV, provided a probability for picking up $s\bar{s}$ pairs from the vacuum of 0.14 is used instead of the standard value of 0.2. In several respects $K^0$ production parallels charged particle production; in the continuum energy dependence, in the increase at the $\Upsilon$ resonance, and in the relative behavior of the momentum dependence for continuum and $\Upsilon$-direct events.

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