Studies of $K_S^0 \to \pi e \nu$ with CMD-2 *

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The decay $K_S^0 \to \pi e \nu$ has been observed by the CMD-2 detector at the e^+e^- collider VEPP-2M at Novosibirsk. Of 6 million produced $K_L^0 K_S^0$ pairs, 75 ± 13 events of the $K_S^0 \to \pi e \nu$ decay were selected. The corresponding branching ratio is $B(K_S^0 \to \pi e \nu)=(7.2 \pm 1.4)\times 10^{-4}$. This result is consistent with the evaluation of $B(K_S^0 \to \pi e \nu)$ from the K_L^0 semileptonic rate and K_S^0 lifetime assuming $\Delta S = \Delta Q$.

While semileptonic decays of the K_L^0 have been well measured, the information on similar decays of K_S^0 is scarce. The only measurement of the $K_S \to \pi^\pm e^\mp \nu$ performed long ago assumed $\Delta S = \Delta Q$ and has low accuracy [1]. The Review of Particle Physics evaluates the corresponding decay rate indirectly, using the K_L^0 measurements and assuming that $\Delta S = \Delta Q$ so that
$\Gamma(K_S^0 \to \pi^\pm e^\mp \nu) = \Gamma(K_L^0 \to \pi^\pm e^\mp \nu)$ [2].
We present results of the direct measurement of the branching ratio for the $K_S^0 \to \pi e \nu$ using the unique opportunity to study events containing a pure $K_L^0 K_S^0$ state produced in the reaction $e^+e^- \to \phi \to K_L^0 K_S^0$. The data were collected during the period of 1993-1998 with the CMD-2 detector [3,4].

Some characteristics of the detector relevant to this analysis are:

- Charged particles from the neutral kaon decays have momenta less than 290 MeV/c and stop within the CsI crystals.
- The DC has momentum resolution of 3% for 200 MeV/c charged particles.
- The CsI calorimeter is placed at a distance of 40 cm from the beam axis and about a half of K_L^0 mesons with the decay length $\lambda = 3.3$ m have interactions within CsI crystals.
- The vacuum beam pipe with a radius of 1.8 cm is placed inside the DC and K_S^0 mesons with the decay length $\lambda = 0.6$ cm decay within it.

K_S^0 decays can be tagged using the presence of the second vertex with two charged particles at a distance from the e^+e^- interaction region or the CsI cluster from K_L^0 interactions in CsI. The most probable decay channel $K_S^0 \to \pi^+\pi^-$ was used for the normalization of the semileptonic $K_S^0 \to \pi e \nu$ decay. Both channels have a vertex with two charged particles near the beam axis.

To identify electrons in the decay under study, we use the difference between measured momentum and energy loss in the detector material for stopped particles. The basic parameter used for charged particle identification was

$$DPE = P_{particle} - E_{loss} - E_{cluster},$$

where $P_{particle}$ is the particle momentum measured in the DC, E_{loss} is the ionization energy loss (about 10 MeV) in the material in front of the CsI calorimeter, $E_{cluster}$ is the energy deposition in the CsI cluster matched with a particle track. CsI clusters which do not match any track are further referred to as photons. Electrons must have DPE=0 if the resolution of the detector is ideal and the leakage of showers in the CsI calorimeter is negligible. On the other hand, pions and positive muons have a broad distribution displaced from zero. Negative muons have a sharp peak displaced from zero as the energy of the CsI cluster is equal to the difference between the muon kinetic energy and E_{loss}. Pions from the decay $K_S^0 \to \pi^+\pi^-$ were used to obtain the distribution over this parameter for charged pions in the

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momentum range 160 - 200 MeV/c. This distribution together with the fitting function is shown in Fig.1. For electrons and muons the distribution over this parameter was obtained from experimental data for reactions $e^+e^- \to e^+e^-, \mu^+\mu^-$ at the beam energy of 195 MeV. At this energy particle momenta are 195 MeV/c for electrons and 164 MeV/c for muons. The DPE distribution for electrons as well as the fitting function are shown in Fig.2. The same distribution for muons (Fig.3 and Fig.4) overlaps with the distribution for pions and this is properly taken into account.

Some kinematic features for the decay mode $K_S^0 \to \pi e \nu$ are :

- The opening angle between two tracks is between 0 and π (Fig.5)
- The momenta of charged particles are less than 290 MeV/c
- The total energy of charged particles (assuming that both particles are charged pions) is between 330 and 550 MeV (Fig.7).

The same parameters for the decay mode $K_S^0 \to \pi^+\pi^-$ are :

- The opening angle between two tracks is more than 2.6 radians (Fig.6)
- The pion momenta are between 160 and 270 MeV/c
- The total energy of charged particles (assuming that both particles are charged pions) is equal to the beam energy (between 508 and 512 MeV) (Fig.8).

The selection criteria for both modes of K_S^0 decay were:

- One or two vertices are found in the event
- Two minimum ionizing tracks with the opposite charge sign are reconstructed from the first vertex (nearest to the beam) and there is no other track with distance to the beam less than 1.4 cm
- The distance from the first vertex to the beam is between 0.2 cm and 1.4 cm. This cut rejects background from the beam region and material of the beam pipe
- The distance from the first vertex to the interaction point along the beam direction is less than 7 cm
- Each charged particle at the first vertex has a momentum between 90 and 270 MeV/c since particles with a momentum less than

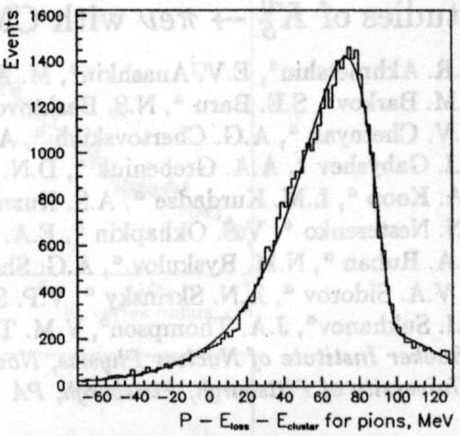

Figure 1. DPE distribution for pions with momenta 160–200 MeV/c in $K_S^0 \to \pi^+\pi^-$ decay.

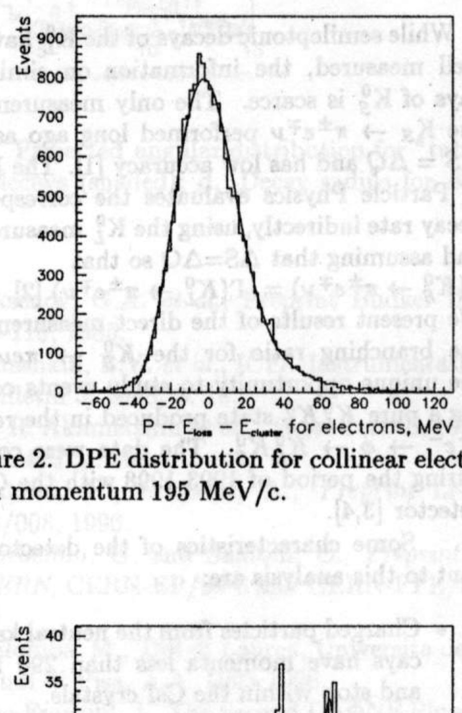

Figure 2. DPE distribution for collinear electrons with momentum 195 MeV/c.

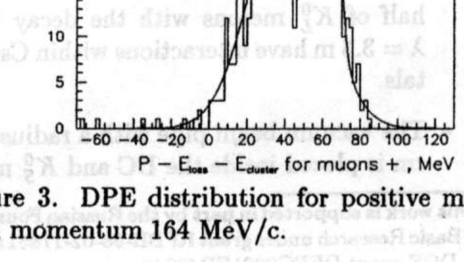

Figure 3. DPE distribution for positive muons with momentum 164 MeV/c.

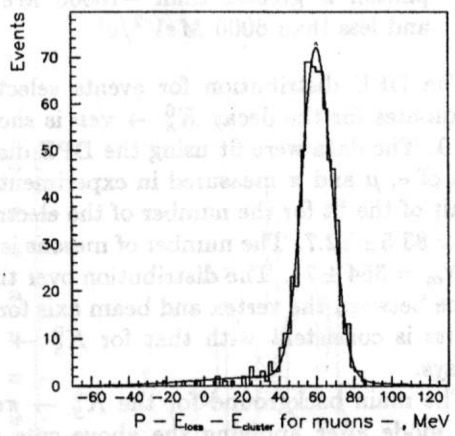

Figure 4. DPE distribution for negative muons with momentum 164 MeV/c.

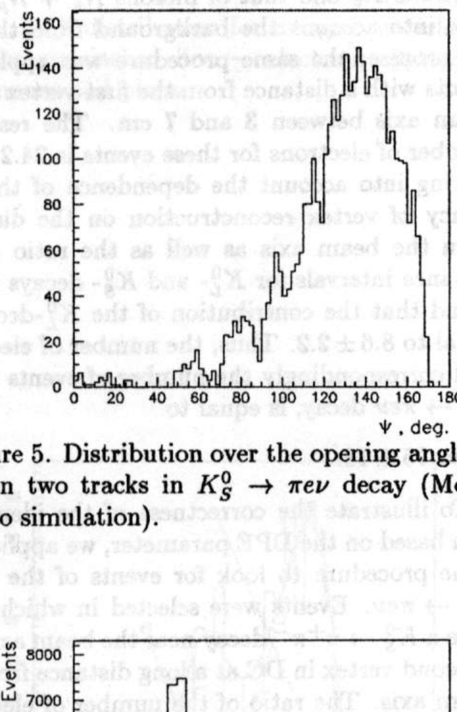

Figure 5. Distribution over the opening angle between two tracks in $K_S^0 \to \pi e \nu$ decay (Monte-Carlo simulation).

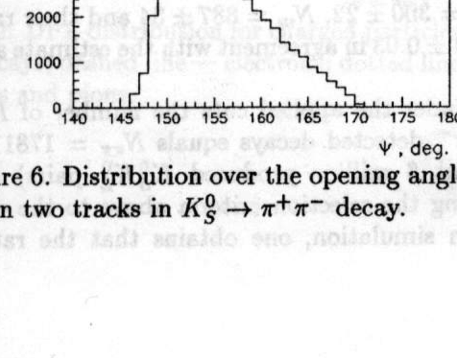

Figure 6. Distribution over the opening angle between two tracks in $K_S^0 \to \pi^+\pi^-$ decay.

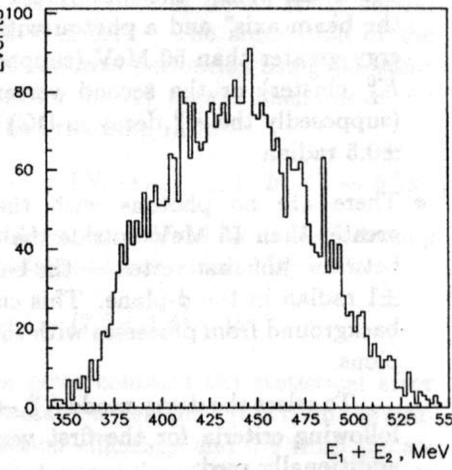

Figure 7. Distribution over the sum energy of charged particles in $K_S^0 \to \pi e \nu$ decay (Monte-Carlo simulation).

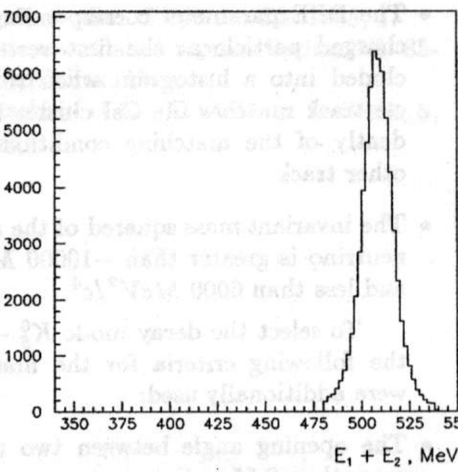

Figure 8. Distribution over the sum energy of charged particles in $K_S^0 \to \pi^+\pi^-$ decay.

90 MeV/c can not reach the CsI calorimeter in the magnetic field of the detector

- **Each track from the first vertex crosses all sensitive layers in the DC along the radial direction and therefore has a polar angle θ between 0.87 and 2.27 radians**

- **Each charged particle at the first vertex fires the ZC and does not fire the muon range system**

- **The azimuthal angle difference between two tracks at the first vertex ($\Delta\phi$) is between 0.17 and 2.97 radians**

- The azimuthal angle difference ($\Delta\phi$) between the plane "the first vertex (K_S^0) — the beam axis" and a photon with the energy greater than 50 MeV (supposedly the K_L^0 cluster) or the second vertex in DC (supposedly the K_L^0 decay in DC) is within ± 0.5 radian
- There are no photons with the energy greater than 15 MeV outside the direction between "the first vertex — the beam axis" ± 1 radian in the ϕ-plane. This cut rejects background from processes with the neutral pions.

To select the decay mode $K_S^0 \to \pi e \nu$ the following criteria for the first vertex were additionally used:

- The opening angle between two tracks is between 0.35 and 2.50 radians
- The total energy of charged particles (assuming that both particles are charged pions) is between 300 and 470 MeV
- The DPE parameter corresponding to the charged particle at the first vertex is included into a histogram when this particle track matches the CsI cluster independently of the matching conditions of the other track
- The invariant mass squared of the assumed neutrino is greater than $-10000\ MeV^2/c^4$ and less than $6000\ MeV^2/c^4$.

To select the decay mode $K_S^0 \to \pi^+\pi^-$ the following criteria for the first vertex were additionally used:

- The opening angle between two tracks is more than 2.55 radians
- The total energy of charged particles (assuming that both particles are charged pions) is between 480 and 540 MeV
- The pion momenta are between 140 and 270 MeV/c
- The average momentum of two charged pions is between 190 and 230 MeV/c
- The ratio of the smaller momentum to the larger one is more than 0.58
- The angle between the vector sum of momenta and the direction "the beam axis $\to$ the first vertex" is less than $\pi/2$
- Each charged particle at the first vertex has a matched CsI cluster
- The invariant mass squared of the assumed photon is greater than $-10000\ MeV^2/c^4$ and less than $6000\ MeV^2/c^4$.

The DPE distribution for events selected as candidates for the decay $K_S^0 \to \pi e \nu$ is shown in Fig.9. The data were fit using the DPE distribution of e, μ and π measured in experiment. The result of the fit for the number of the electrons is $N_e = 83.5 \pm 12.7$. The number of mesons is equal to $N_m = 354 \pm 21$. The distribution over the distance between the vertex and beam axis for these events is consistent with that for $K_S^0 \to \pi^+\pi^-$ decays.

The main background for the $K_S^0 \to \pi e \nu$ decay mode after applying the above cuts comes from the decays $K_S^0 \to \pi^+\pi^-\gamma$, $K_S^0 \to \pi\mu\nu$ and $K_L^0 \to \pi e \nu$. The former two processes are taken into account while fitting the histogram over DPE (the fit has two free parameters - the number of electrons N_e and that of mesons $N_\pi + N_\mu$). To take into account the background from the latter process, the same procedure was applied to events with a distance from the first vertex to the beam axis between 3 and 7 cm. The resulting number of electrons for these events is 24.2 ± 6.1. Taking into account the dependence of the efficiency of vertex reconctruction on the distance from the beam axis as well as the ratio of the distance intervals for K_L^0- and K_S^0- decays it was found that the contribution of the K_L^0-decays is equal to 8.6 ± 2.2. Thus, the number of electrons and correspondingly the number of events of the $K_S^0 \to \pi e \nu$ decay, is equal to

$N_e = 75 \pm 13$.

To illustrate the correctness of the identification based on the DPE parameter, we applied the same procedure to look for events of the decay $K_L^0 \to \pi e \nu$. Events were selected in which there were a $K_S^0 \to \pi^+\pi^-$ decay near the beam axis and a second vertex in DC at a long distance from the beam axis. The ratio of the number of electrons N_e to the number of pions and muons $N_\mu + N_\pi$ can be calculated from the branching ratios of the main decay modes of the K_L^0 and should be equal to 0.33 [2]. The DPE distribution for events selected as candidates for the decays of K_L^0 meson is shown in Fig.10. The results of the fit are: $N_e = 300 \pm 22$, $N_m = 887 \pm 34$ and their ratio is 0.34 ± 0.03 in agreement with the estimate above.

Under the applied cuts the number of $K_S^0 \to \pi^+\pi^-$ detected decays equals $N_{\pi\pi} = 178110$ (of about 6 million produced $K_S^0 K_L^0$ pairs). Applying the selection criteria above to the events from simulation, one obtains that the ratio of

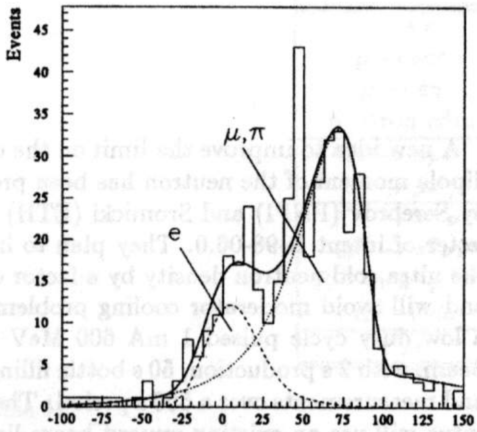

Figure 9. DPE distribution for charged particles in K_S^0 decays; dashed line — electrons; dotted line — muons and pions.

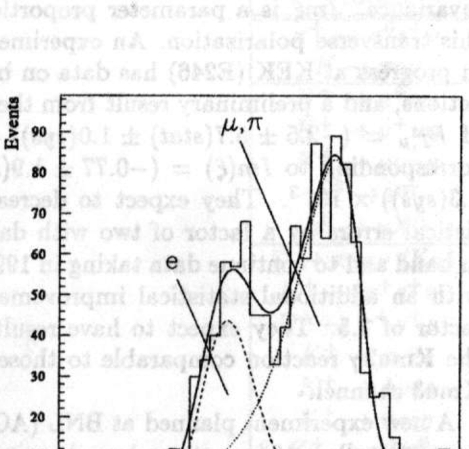

Figure 10. DPE distribution for charged particles in K_L^0 decays; dashed line — electrons; dotted line — muons and pions.

the detection efficiency for the normalization process to one for the process under study should be $\varepsilon_{rel} = 2.49 \pm 0.12$. The simulation of the $K_S^0 \to \pi e \nu$ decay was performed using the same Dalitz plot as for the K_L^0 decay. Then one would expect for the branching ratio

$$B(K_S^0 \to \pi e \nu) = (N_e \cdot \varepsilon_{rel}/N_{\pi\pi}) \cdot B(K_S^0 \to \pi^+\pi^-).$$

From 75 ± 13 events observed by us the following result was obtained for the branching ratio:

$$B(K_S^0 \to \pi e \nu) = (7.2 \pm 1.4) \times 10^{-4}.$$

The qiven error contains the statistical error and the systematic uncertainty (5% from the simulation detection efficiency and 5% from the selection criteria) added in quadrature. This result is consistent with the previous determination of $B(K_S^0 \to \pi e \nu)$ [1] as well as with the Review of Particle Physics evaluation [2].

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