Study of the $K_S^0 K_L^0$ couple decays with CMD-2

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About 20 millions of ϕ decays were used to study $K_S^0 K_L^0$ coupled decays with the CMD-2 detector at VEPP-2M collider. The regeneration cross section for 110 MeV/c momentum kaons on Be was found to be σ_{reg}^{Be}=55.1±7.7 mb. The angular distribution of regenerated events has been measured.

1. Introduction

The CMD-2 detector is operating now at the VEPP-2M collider[1] and it has been described in more detail elsewhere [2,3]. A 3.4 cm diameter vacuum beam pipe is made of Be 0.077 cm thick and it may be considered here as the target for studies of kaon nuclear interaction.

The integrated luminosity of 15 pb^{-1}, corresponding to about 22.0×10^6 produced ϕ's has been analysed. Some preliminary results on the study of $K_S^0 K_L^0$ coupled decays with the CMD-2 detector based on a relatively small data sample have already been published [4]. In this paper we present recent results in the study of coupled $K_S^0 K_L^0$ decays and interactions, including a better measurement of the regeneration cross section.

2. Selection of $K_S^0 K_L^0$ coupled decays

Candidates were selected from a sample in which two vertices were found within 15 cm from the beam axis, each with two opposite charged tracks . Tracks in both vertices should have an acollinearity angle higher than 0.1 radians. An example of such event is shown in Figure 1. Figure 2a shows the lego plot of invariant mass M_{inv} vs. missing momentum P_{mis} for tracks in the "closest to the beam" vertex assuming them to be pions. The peak at the kaon mass and kaon momentum shows that the decay $K_S^0 \to \pi^+\pi^-$ dominates in the first vertex.

The cuts $470 < M_{inv} < 525 MeV/c^2$ and $80 < P_{mis} < 140 MeV/c$, plus the additional requirement to have another reconstructed vertex in the missing momentum direction, select $K_S^0 \to \pi^+\pi^-$ events in one of the vertices. In this case K_L^0 is expected to be in the other one. With these conditions about 14,000 events with double vertices have been selected.

Figure 2b shows the lego plot $M_{inv} vs. P_{mis}$ for tracks in the second vertex when the $K_S^0 \to \pi^+\pi^-$ decay is selected in the first one with the above cuts. The three body decay distribution dominates, but the peak at the kaon mass is seen, demonstrating the presense of a two pion final state in both vertices.

Figure 3a shows the decay length distribution for selected $K_S^0 \to \pi^+\pi^-$ events, compared the expected one with the decay length of 0.54±0.01 cm averaged over beam energy.

The decay radius distribution for the K_L^0's with two charged tracks in the final state is shown in Figure 3b. The K_L^0 has the decay length about 350 cm - much longer than detector dimensions and a dashed line shows the expected number of K_L^0 decaying in flight if the reconstructed efficiency assumed to be uniform. As soon as the K_L^0 enters the material of the beam pipe, a sharp peak with 562 ± 43 events is seen, starting at the radius of 1.7 cm corresponding to K_L^0 interactions

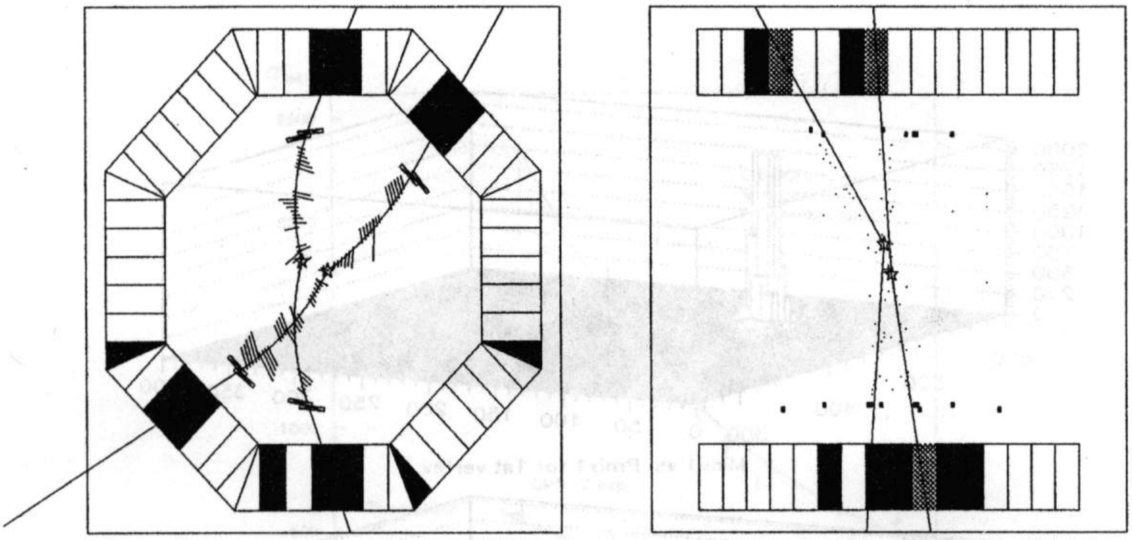

Figure 1. Display of the $\phi \to K_S^0 K_L^0$ event with a coupled decay.

with nuclei in the Be pipe, following with a broad distribution with about 1100 events expecting to be interactions with DC material (Cu-Ti wires and Ar gas). The remaining events are K_L^0 decays in flight. All three major charged modes are clearly seen (histograms are not shown).

To select candidates for $K_L^0 \to \pi^+\pi^-$ events, an additional cut requiring the invariant mass of two tracks from a K_L^0 vertex to be in the range of 470-525 MeV/c^2 was applied. The obtained distribution is shown in Figure 3d, together with the fit function showing the flat distribution for K_L^0 semileptonic decays, remaining after applied cuts, as well as a peak, starting at 1.7 cm and described by an exponential function with K_S^0 decay length. 238 ± 20 events under the peak are interpreted as the regeneration of K_L^0 into K_S^0 at the Be pipe.

One can apply stronger requirements for these events to satisfy $K_L^0 \to \pi^+\pi^-$ kinematics within the detector resolution, i.e. $80 MeV/c < P_{mis} < 140 MeV/c$ and the K_S^0 vertex being in the P_{mis} direction. This selection is illustrated in Figure 3d by histogram. The peak at the Be pipe survives with 91±12 events and about 180 K_L^0 decays in flight and interactions in DC material remain. About 40 CP violation decays of $K_L^0 \to \pi^+\pi^-$ are expected but cannot be identified because of K_L^0 semileptonic decays background and nuclear interactions.

3. Cross sections calculation

Using the number of events above and simulated efficiencies for estimation of the total number of K_L^0 passed through the Be pipe (detailes see in [4], the following cross sections for the regeneration and visible inelastic scattering have been obtained:

$\sigma_{reg}^{Be} = 55.1 \pm 5.9 \pm 5.0$ mb.

$\sigma_{inel}^{Be,vis} = 72 \pm 9$ mb.

The sources of the inelastic scattering events are reactions with Σ and Λ production. About 10% admixture of these reactions to regenerated events and corrections for the presence of other material (0.1 mm mylar DC window) are the main contribution to the systematic error.

To estimate the total cross section, the relative weight of these reactions was taken to be 0.21 from the CERN GEANT code (NUCRIN). With the ratio $\sigma_{inel}/\sigma_{tot} = 0.52$ taken from [5], one can estimate $\sigma_{tot}^{Be} = 580 \pm 72 \pm 174$ mb. The comparison of the obtained cross section with other experiments and calculations is shown in Fig.4.

The histogram in Figure 3c shows the angular distribution (in the $r - \phi$ plane) for the K_S^0 regenerated at the beam pipe (events at 1.5 - 4.0 cm) after subtraction of the background from the semileptonic decays of K_L^0 (events at 4.0 - 6.5 cm). The obtained angular distribution is wider than in the case of coherent regeneration which can be illustrated by the distribution shown by histogram for original K_S^0 decays at the same distance. There is no evidence for the coherent contribution to the regenerated events.

The data were obtained at different energies around the ϕ. The regeneration cross section can be calculated for different kaon momenta. For

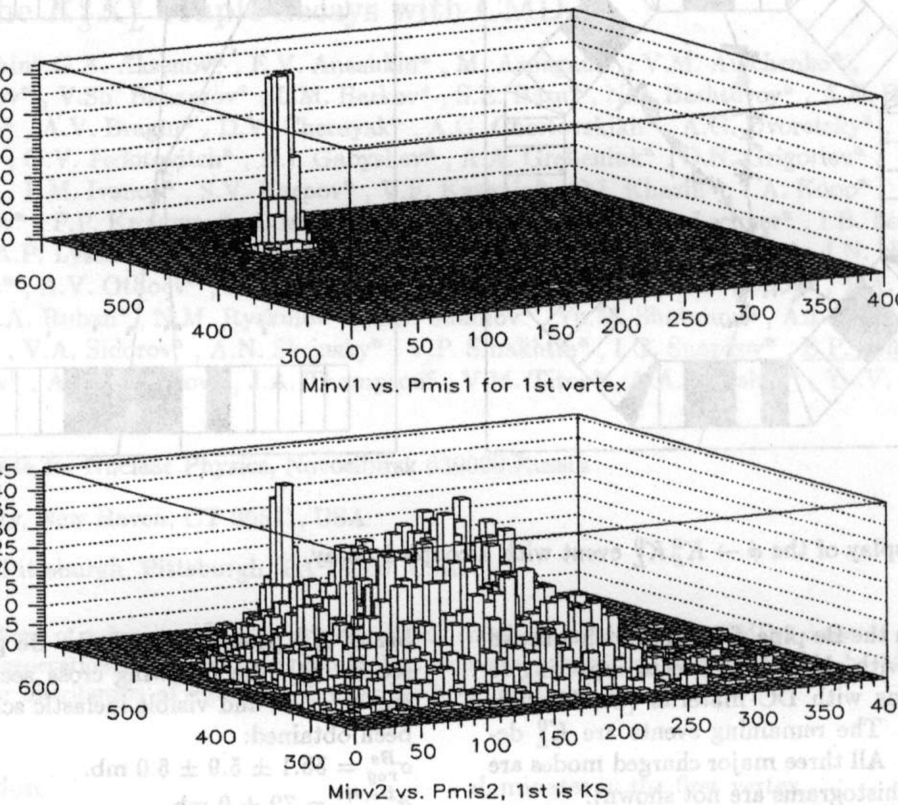

Figure 2. a. The $M_{inv} vs. P_{mis}$ distribution for tracks in first vertex; b. The $M_{inv} vs. P_{mis}$ distribution for tracks in second vertex when K_S is selected in first vertex.

the average momenta 105±2, 110±2 and 115±2 Mev/c the cross sections 51.9±8.5, 63.5±7.4 and 48.0±10.5 mb have been obtained respectively.

4. Discussion

The selection of candidates for $K_L^0 \to \pi^+\pi^-$ events faced two problems. First was a background from the dominant semileptonic K_L^0 decays which already was discussed in [6] and seemed to be solvable with better DC resolution.

A second problem was relatively high background from nuclear interactions of K_L^0 and regeneration effect which was for the first time experimentally observed for slow kaons with the CMD-2 detector.

In Figure 5a the measured regeneration cross section is plotted together with the theoretical calculations [5] for Be and Cu. The comparison of the calculated regeneration cross sections for these two different materials shows, that at momenta below 200 MeV/c one cannot scale them by a simple $A^{2/3}$ dependence. Unfortunately, our momentum range is too narrow to prove it experimentaly. The obtained regeneration cross section for Be within experimental errors is in agreement with the theoretical calculations.

The experimental angular distribution of the regenerated K_S^0 after background subtraction is presented in Figure 5b together with a fitted exponential function and theoretical prediction [5] and seems to be in relatively good agreement.

The regeneration influence was discussed[5,7] for the ϵ'/ϵ measurement planned in KLOE detector[8]. It was shown that the total number of regenerated in the KLOE drift chamber events (dominated by He+10% iC_4H_{10} gas) contribute 17% to the number of CP-violating $K_L^0 \to \pi\pi$ decays. But due to the broad distribution of the regenerated events (about 60^o average difference with initial direction compare to about 1^o resolution for DC and 14^o for calorimeter) effective angular cuts can be applied. The cut at 30^o decreases the contamination by factor of 20.

The regeneration itself does not give any decay asymmetry expected for the direct CP violating K_L^0 decay, but the selection cuts applied to $\pi^+\pi^-$

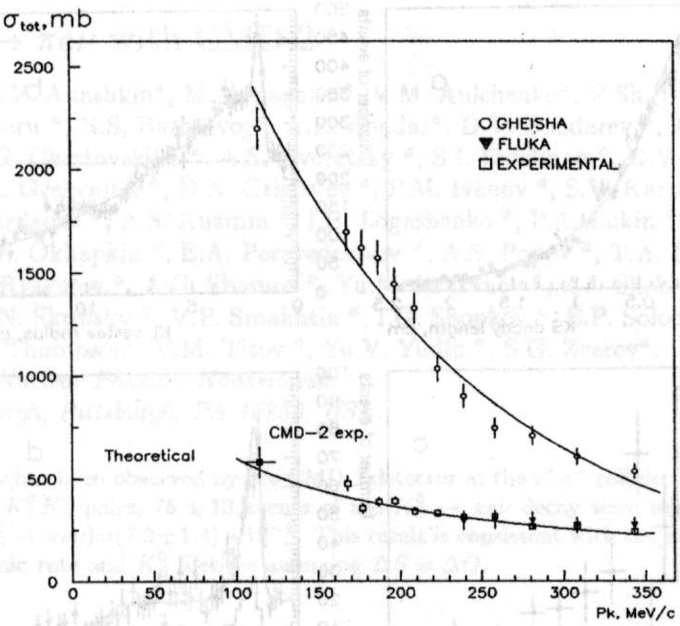

Figure 4. Comparison of total nuclear cross section for K_L with different simulation packages. Experimental points at higher momenta are shown. Theoretical line represents calculations from [5].

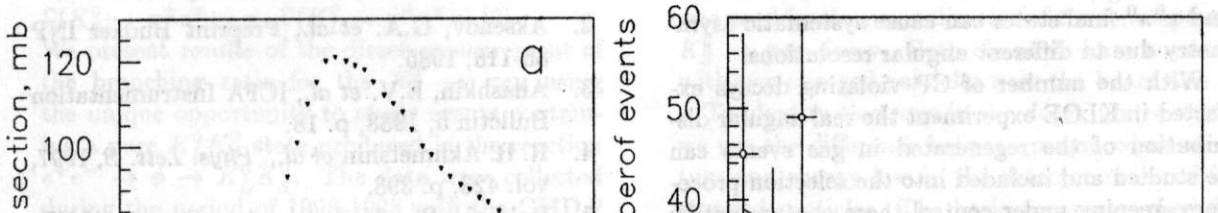

Figure 5. a. Experimental regeneration cross section and theoretical calculations for Be and Cu; b. Projected angular distribution of the regenerated K_S^0 with fit function (solid line) and theoretical prediction (dots);

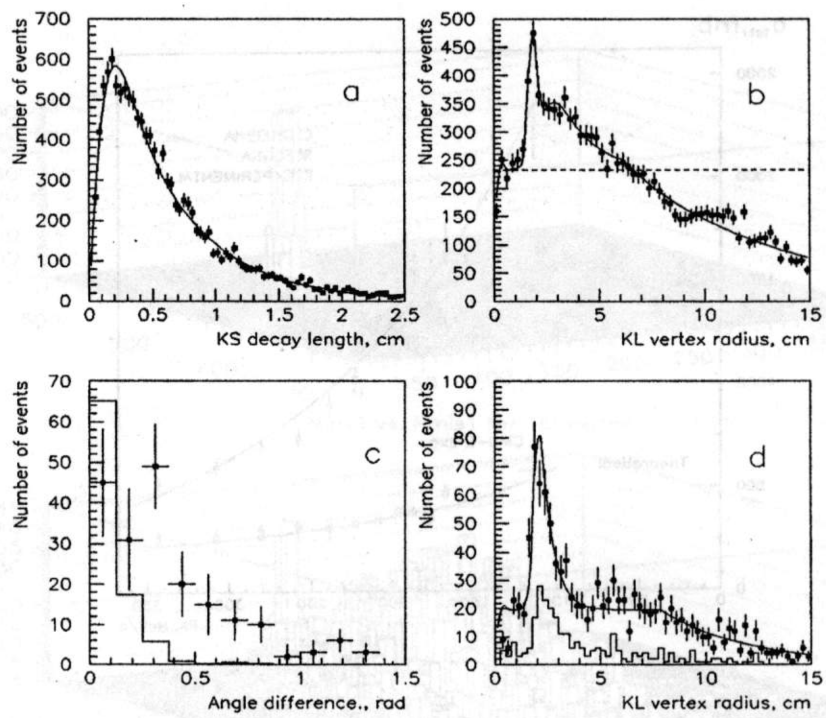

Figure 3. a. Decay length for K_S^0; b. Decay radius for K_L^0; c. Projected angular distribution for "tube" events after background subtraction and for K_S^0 two pions decays (shaded); d. Decay radius for K_L^0s after M_{inv} cut and after K_S^0 selecting cut (histogram).

and $\pi^0\pi^0$ final states can cause systematic asymmetry due to different angular resolutions.

With the number of CP violating decays expected in KLOE experiment the real angular distribution of the regenerated in gas events can be studied and included into the selection procedure, keeping under control there contamination to charged and neutral mode.

5. Summary

Study of the $K_S^0 K_L^0$ couple decays with the CMD-2 detector gives improved value for the regeneration cross section of 110 MeV/s kaons on the Be to be 55.1±7.7 mb. The total nuclear interaction cross section was found to be $\sigma_{tot}^{Be} = 580 \pm 72 \pm 174$ mb.

It is shown that within experimental errors the cross sections and angular distribution are in agreement with theoretical expectations[5]. It is proved, that the latter can be used for regeneration background estimation in KLOE experiment.

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