STUDY OF THE K_SK_L COUPLED DECAYS AND K_L-Be INTERACTIONS AND RELEVANCE TO FUTURE CP, CPT Φ-FACTORY STUDY

R.R.AKHMETSHIN, G.A.AKSENOV, E.V.ANASHKIN, M.ARPAGAUS, V.A.ASTAKHOV, V.M.AULCHENKO, B.O.BAIBUSINOV, V.S.BANZAROV, L.M.BARKOV, S.E.BARU, A.E.BONDAR, D.V.CHERNYAK, V.V.DANILOV, S.I.EIDELMAN, G.V.FEDOTOVICH, N.I.GABYSHEV, A.A.GREBENIUK, D.N.GRIGORIEV, B.I.KHAZIN, I.A.KOOP, A.S.KUZMIN, M.LECHNER, I.B.LOGASHENKO, P.A.LUKIN, A.P.LYSENKO, A.V.MAKSIMOV, Yu.I.MERZLYAKOV, I.N.NESTERENKO, V.S.OKHAPKIN, E.A.PEREVEDENTSEV, A.A.POLUNIN, E.V.POPKOV, V.I.PTITZYN, T.A.PURLATZ, S.I.REDIN, N.I.ROOT, A.A.RUBAN, N.M.RYSKULOV, Yu.M.SHATUNOV, M.A.SHUBIN, B.A.SHWARTZ, V.A.SIDOROV, A.N.SKRINSKY, V.P.SMAKHTIN, I.G.SNOPKOV, E.P.SOLODOV, A.I.SUKHANOV, V.M.TITOV, Yu.V.YUDIN, V.G.ZAVARZIN

Budker Institute of Nuclear Physics, Novosibirsk, 630090, Russia

D.H.BROWN, J.P.MILLER, B.L.ROBERTS, W.A.WORSTELL

Boston University, Boston, MA 02215, USA

J.A.THOMPSON, C.M.VALINE

University of Pittsburgh, Pittsburgh, PA 15260, USA

P.B.CUSHMAN

University of Minnesota, Minneapolis, Minnesota 55455, USA

S.K.DHAWAN, V.W.HUGHES

Yale University, New Haven, CT 06511, USA

The integrated luminosity $\approx 4000nb^{-1}$ of around ϕ meson mass ($5.0\times10^6 of \phi$'s) has been collected with the CMD-2 detector at the VEPP-2M collider. A latest analysis of the K_SK_L coupled decays and search of CP-violating decay $\eta \to \pi^+\pi^-$ based on 30% of available data are presented in this paper. A selection of $K_L \to \pi^+\pi^-$ decays demonstrated background from semileptonic K_L decays and the regeneration of K_L into K_S at the Be vacuum pipe. The regeneration cross section for 110 MeV/c kaons has been measured along with angular distribution.

1 Introduction

As it was realized at the very early steps of the ϕ meson studies at the colliding beam machines, K_SK_L pairs can be used for studying CP and CPT violation. These suggestions, including studies of quantum mechanical correlations, were discussed in [1,2] for experiments at VEPP-2M[3], an electron-positron collider at the Budker Institute of Nuclear Physics in Novosibirsk, Russia and carefully reviewed by [4].

The ϕ resonance produced in e^+e^- collisions can also be considered as a source of the η,η' mesons[5] and the low momentum neutral and charged kaon pairs for studies of nuclear interactions.

The construction of the ϕ-factories in Novosibirsk and Frascati [6,7] will make feasible new precise measurements of a possible direct component in the decay $K_L \to \pi^+\pi^-, \pi^0\pi^0$ (ϵ'/ϵ).

At the VEPP-2M collider with the peak luminosity $L \approx 5. \times 10^{30} cm^{-2}s^{-1}$ which could be considered as a pre ϕ-factory with the CMD-2 detector some usefull measurements can be done to prepare for running at the ϕ-factories. An upgrade of the collider to $10^{32} cm^{-2}s^{-1}$ luminosity has been

planned for investigating the idea of the round beams, an important ingredient of the Novosibirsk ϕ-factory project[8].

The CMD-2 detector has been described in more detail elsewhere [2,9]. A 3.4 cm diameter vacuum beam pipe is made of Be with a 0.077 cm wall thickness and may be considered as a target for studies of the kaon nuclear interaction.

The integrated luminosity of 1500 nb^{-1} (about 30% of available data) has been analyzed around ϕ corresponding to about 1.7×10^6 produced ϕ's. Some preliminary results were published in [10].

2 Selection of $K_S K_L$ coupled decays

Candidates were selected from a sample in which two vertices, each with two opposite charge tracks, were observed within 15 cm from the beam axes and all tracks were reconstructed. An example of such event is shown in Figure 1.

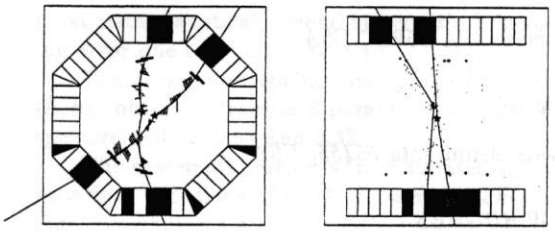

Figure 1: $\phi \to K_S K_L$ event with coupled decay.

The cuts $470 MeV/c^2 < M_{inv} < 525 MeV/c^2$ and $80 MeV/c < P_{mis} < 140 MeV/c$ with an additional requirement to have another reconstructed vertex in the P_{mis} direction select $K_S \to \pi^+\pi^-$ events in one of the verteces. In this case K_L is expected to be in the other one.

Figure 2a shows the decay length distribution for selected K_S's with the correct 0.55±0.02 cm decay length. The decay radius distribution for the K_L's with two charged tracks in final state is shown in Figure 2b. At the flat region, where reconstruction efficiency is uniform, a peak is seen at the radius of 1.7 cm corresponding to the 79 ± 18 of K_L's which interacted with nuclei in the Be tube. The remain 1355 events are representing K_L decaying in flight.

To select candidates to $K_L \to \pi^+\pi^-$ events additional cut requiring the invariant mass of two tracks from a K_L vertex to be in the range of 470-

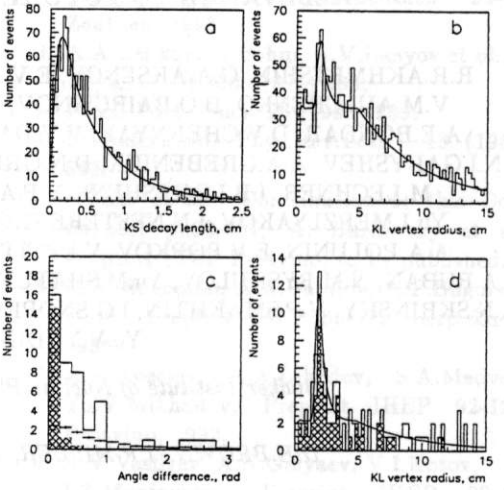

Figure 2: a. Decay length for K_S; b. Decay radius for K_L; c. Projected angular distribution for "tube"events (histogram), K_L semileptonic decays (points with errors and K_S two pions decays (shaded); d. Decay radius for K_Ls after M_{inv} cut and after K_S selecting cut (shaded).

525 MeV/c^2 was applied. The obtained distribution is presented in Figures 2d together with the fit function where all parameters except the number of events are fixed at the values obtained from the distribution in Figure 2b. The number of events under the peak drops down to 31 ± 7 and 78 remains from K_L decays in flight. One can apply stronger requirements for these events to satisfy $K_L \to \pi^+\pi^-$ kinematics within detector resolution, i.e. $80 MeV/c < P_{mis} < 140 MeV/c$ and K_S vertex in the P_{mis} direction. This selection is illustrated in Figure 2d by shaded histogram. The peak at the Be tube survives with 20±5 events and 35 K_L decays in flight remain.

The 28.5 ± 6.4 events found in the peak after the invariant mass cut and some efficiency corrections are interpreted as regeneration of K_L into K_S with its decay into $\pi^+\pi^-$ and another 50 ± 17 peak events represents nuclear interactions with two visible charged particles.

Using simulated efficiencies for estimation of full number of K_L passed berillium pipe, the following cross sections for regeneration and visible inelactic scattering have been obtained:
$\sigma^{Be}_{reg} = 58 \pm 17$ mb.
$\sigma^{vis}_{inel} = 77 \pm 26$ mb.

The sources of the inelastic scattering events are the reactions with Σ and Λ production. To estimate the total cross section, the relative weight of these reactions was taken 0.21 from the CERN GEANT code (NUCRIN). With the ratio $\sigma_{inel}/\sigma_{tot} = 0.52$ [11], one can estimate $\sigma_{tot}^{Be} = 705 \pm 238$ mb.

A histogram in Figure 2c shows the projected angular distribution for the regenerated at the beam pipe K_S along with the background from the semileptonic decays of K_L (dots with errors). The obtained angular distribution is wider than in the case of coherent regeneration which can be illustrated by the shown shaded distribution for original K_S decays at the same distance. But with the available sample coherent contamination cannot be extracted.

3 Discussion

The selection of candidates for $K_L \to \pi^+\pi^-$ events faced two problems. First was a background from the dominant semileptonic K_L decays which already was discussed in [12] and seemed to be solvable with better DC resolution.

A second problem was relatively high background from nuclear interactions of K_L and regeneration effect which was first time experimentaly observed for slow kaons.

In Figure 3a the experimental regeneration cross section is plotted together with the theoretical calculations for Be and Cu performed in [11]. 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. The experimental angular distribution of the regenerated K_S after background subtraction is presented in Figure 3b together with the fit function and theoretical prediction [11] and seems to be more narrow.

The obtained experimental value of the total nuclear cross section in Be for a 110 MeV/c kaons is shown in Figure 4 together with the experimental data at higher momenta [13] and theoretical calculations [11]. The cross sections extracted from GHEISHA and FLUKA simulation codes are also shown. It is seen that the FLUKA code, as well as the calculations from [11] are in good agreement with experimental data. The GHEISHA

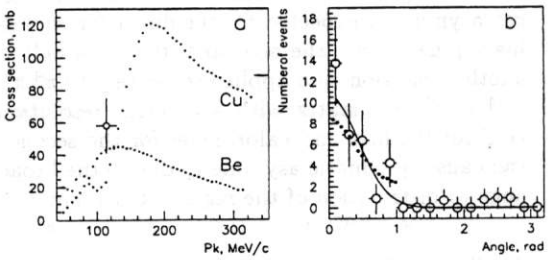

Figure 3: a. Experimental regeneration cross section and theoretical calculations for Be and Cu; b. Projected angular distribution of the regenerated K_S with fit function (solid line) and theoretical prediction (dots);

code gives completely wrong absolute value as well as momentum dependence.

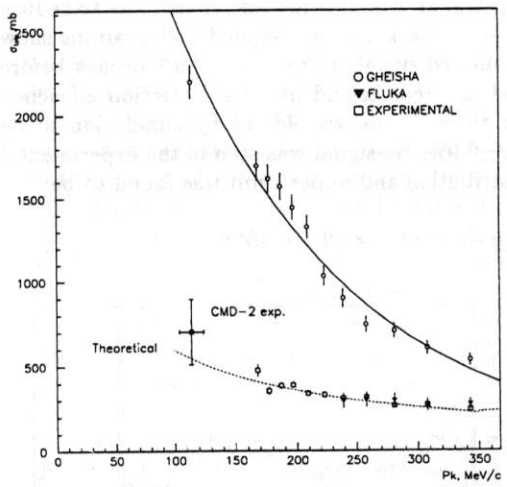

Figure 4: Comparison of the total experimental K_L nuclear interaction cross section in Be with the theoretical calculations and simulation by different codes.

After publishing our preliminary results [10], the regeneration influence was discussed for the ϵ'/ϵ measurement planned in KLOE detector [11]. It was shown that the total regeneration probability in the KLOE drift chamber after an acoplanarity cut (factor of 4 rejection) was 10^{-4} that should be compared with 2×10^{-3} probability for the "normal" CP violating $K_L \to \pi\pi$ decay and $\approx 10^{-6}$ probability for the direct CP violation decay.

The regeneration itself does not give any decay asymmetry expected for the direct CP violating K_L decay, but the acoplanarity cut as well as another selection cuts applied separately to $\pi^+\pi^-$ and $\pi^0\pi^0$ final states with a different resolution (DC for the first and calorimeter for the second) can cause systematic asymmetry due to the broad angular distribution of the regenerated events.

4 Search for $\eta \to \pi^+\pi^-$ decay

As it was mentioned before, the radiative $\phi \to \eta\gamma$ decay can be concidered as a source of η mesons, acompanied with 362 MeV energy gamma.

With analyzed luminosity integral 28056 η's were produced. The selected $\pi^+\pi^-\gamma$ events[14] can be used to search for CP violation decay $\eta \to \pi^+\pi^-$. This decay can be seen as a peak in the photon energy histogramm at the 362 MeV region. Figure 5 shows photon energy distribution after constraind fit and some additional cuts to reduce $\phi \to 3\pi$ backgroung. Shaded histogramms show simulated signals from $\eta \to \pi^+\pi^-$ decays before and after constraind fit. The detection efficiency for these events was found by simulation to be 9.9±0.9%. No signal was seen in the experimental distribution and upper limit was found to be:

$$B(\eta \to \pi^+\pi^-) \; < \; 2.1 \times 10^{-3}.$$

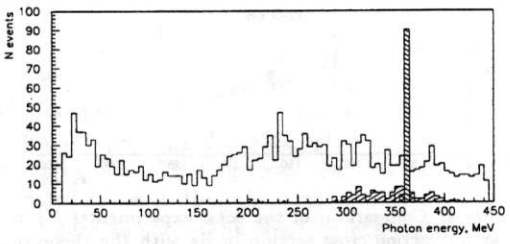

Figure 5: Photon energy for $\phi \to \pi^+\pi^-\gamma$ events to search for $\eta \to \pi^+\pi^-$ decay. Simulated signals before and after constrained fit are shown shaded.

5 Conclusion

With the CMD-2 detector the coupled $K_S K_L$ decays have been observed for the first time.

The measured values of the cross sections indicate that regeneration will cause an additional background for the CP-violating decays of K_L at the ϕ-factory experiments and should be carefully studied to avoid systematic errors.

The search of CP-violation decay $\eta \to \pi^+\pi^-$ based on about 28000 ηs was performed.

Acknowledgements

One of the authors (E.P.Solodov) would like to thank R. Baldini and A. Michetti for useful discussions on the nuclear interaction studies and cooperation in this field.

This work is supported in part by the US Departament of Energy, US National Science Foundation and the International Science Foundation under grants RPT000 and RPT300.

Referencies

1. V.N.Bayer, Russian ZETP **17**, 446 (1973).
2. G.A.Aksenov *et al*, Preprint BudkerINP 85-118, Novosibirsk, 1985.
3. V.V. Anashin *et al*, Preprint BudkerINP 84-114, Novosibirsk, 1984.
4. J.L. Rosner, I. Dunietz, J. Hauser *Phys. Rev.* D **35**, 2166 (1987).
5. S. Eidelman, E. Solodov, and J. Thompson, *Nucl. Phys.* B **24**, 174 (1991).
6. A.N.Skrinsky, Proc. of the Workshop on Physics and Detectors for DAΦNE, Frascati, April, 1991, p. 67.
7. G. Vignola, Proc. of the Workshop on Physics and Detectors for DAΦNE, Frascati, April, 1991, p. 11.
8. A.N.Filippov *et al*, Proc. of the XVth Int. Conf. on High Energy Accelerators, Hamburg, Germany, 1991, World Scientific, V. II, p. 1145.
9. E.V. Anashkin *et al*, ICFA Instrumentation Bulletin 5 (1988), p.18.
10. R.R. Akhmetshin *et al*, Preprint BudkerINP 95-62, Novosibirsk 1995.
11. R. Baldini, A. Michetti, KLOE Memo 30, July 1995.
12. G.Barbellini and C.Santoni, CERN-EP/89-8 and CERN-PPE/90-09.
13. G. A. Sayer and E. F. Beall, *Phys. Rev.* D **169**, 1045 (1968).
14. See talk by E.P.Solodov, this Proceedings, "Hadron Spectroscopy" section.