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# THE PARTIAL WAVE ANALYSIS OF A $K^- \pi^- \pi^+$ SYSTEM COHERENTLY PRODUCED ON NUCLEI AT 40 GeV

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The partial-wave analysis of the $K^- \pi^- \pi^+$ system coherently produced on nuclei in the reaction $K^- A \to K^- \pi^- \pi^+ A$ at the energy 40 GeV has been done. It is shown that only the partial states of the unnatural set contribute to the $K^- \pi^- \pi^+$ system. The features of the intensities and phases of the states with spin-parity $1^+$ indicate that two axial-vector $K\pi\pi$-resonances with masses $\sim 1400$ MeV and $\sim 1300$ MeV are produced. The $0^-$-state manifests its resonant properties at mass $\sim 1460$ MeV which indicates the radial excited state of the kaon production in the reaction under investigation.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

## Парциально-волновой анализ $K^- \pi^- \pi^+$-системы, когерентно образованной на ядрах при энергии 40 ГэВ

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Проведен парциально-волновой анализ $K^- \pi^- \pi^+$-системы, дифракционно образованной на ядрах Be, Al, Cu, Ag, Pb в реакции $K^- A \to K^- \pi^- \pi^+ A$ при энергии налетающего $K^-$-мезона 40 ГэВ. Показано, что в $K^- \pi^- \pi^+$-систему дают вклады только парциальные состояния ненатуральной серии ($0^-$, $1^+$, ...). Характер поведения спектров интенсивностей состояний со спин-четностью $1^+$ и их относительных фаз свидетельствует об образовании двух аксиально-векторных

резонансов $Q_a$ и $Q_b$ с массами ~ 1400 МэВ и ~ 1300 МэВ соответственно. В псевдоскалярном состоянии $0^-$ проявляются резонансные свойства при массе ~ 1460 МэВ, что указывает на образование радиально-возбужденного состояния каона в исследуемом процессе.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

## 1. Introduction

The results of the partial-wave analysis of a strange boson $K^- \pi^- \pi^+$ system coherently produced on Be, Al, Cu, Ag and Pb nuclei in the reaction

$$K^- A \to K^- \pi^- \pi^+ A \qquad (1)$$

have been considered.

The experiment has been carried out at the Serpukhov accelerator by Collaboration Bologna-Dubna-Milano. The set-up of the experiment and its performances are described in ref. /1/.

The partial wave structure of the $K\pi\pi$ system was investigated earlier in the high statistic study of diffractive $K\pi\pi$-production on a hydrogen target /2,3/. The results of this analysis indicate the production of two axial-vector resonances $Q_a(1400)$ and $Q_b(1300)$ together with the diffractively produced nonresonant ("Deck" — type) background. The evidence of a broad pseudoscalar resonance at $K\pi\pi$-mass 1.46 GeV was also found, which was interpreted as a radial excited state of the kaon.

The nuclear target has several advantages over the hydrogen one. It was shown /4/ that coherent production on nuclei at high energy enhances the resonant production with respect to the nonresonant background due to the absorption of the nonresonant states in nuclear matter which favours the resonant states. Moreover the partial wave analysis based on the nuclear data is less complicated than that based on the data obtained on the hydrogen target because of the maximal degree of coherence between any pairs of waves and simpler sets of waves due to the strong polarization in the final states.

## 2. Data taking, measurement, selection of events

The events of reaction (1) were detected under the same experimental conditions as it had been done for the process of $3\pi$-production /5/. The momentum of the unseparated beam was 38.7 GeV and $K^-$-mesons

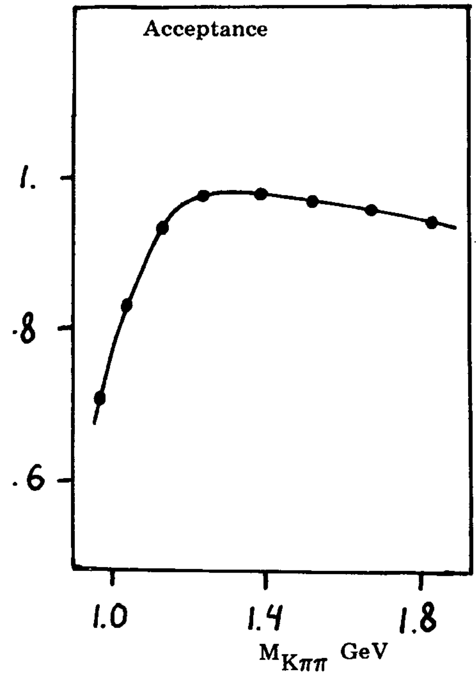


*Fig. 1. Acceptance of the apparatus as a function of mass.*

made up 1.8% of the beam. To identify the beam particles, which create triggers, three gas threshold Cerenkov counters were used. The $\pi^-$-contamination in the selected sample of $K^-$ mesons was less than 3%. The geometrical efficiency of the spectrometer for $K\pi\pi$-detection via momentum transfer $t' = |t - t_{min}|$ to nuclei is flat up to 0.5 $(GeV/c)^2$ and close to 100%, and its dependence on produced $K\pi\pi$-mass is shown in fig.1.

Data handling consisted in measuring the coordinates of the secondaries at the HPD — apparatus and in the geometrical and kinematical reconstruction of events.

The events which belonged to reaction (1) were selected for the next stage of the analysis according to the value of the missing longitudinal momentum, the coordinate of vertex and value of kinematical probability.

Of 96300 triggers 15076 events of the reaction under investigation were included in the partial wave analysis.

The $K\pi\pi$-mass resolution is ~ 30 MeV in the range 1.0 ÷ 1.6 GeV.

Since there was no identification of secondaries in the experiment, each event was presented on the Data Summary Tape with two hypothesis corresponding to two possibilities of mass assignment $M_{K^-}$ and $M_{\pi^-}$ to negatively charged outgoing particles during the kinematic fit of the reaction. The recoil nucleus was not registered and the kinematic fit has one constraint. Therefore the fit probability value is insensitive to the true mass assignment (true hypothesis) and one has to elaborate the criterion to resolve this two-fold ambiguity.

The experimental fact that in the reactions like (1) the outgoing $K^-$ meson is predominantly a leading particle with respect to $\pi^-$ meson, was used for selection of the hypothesis uncluded in the partial wave analysis that followed. The total sample of the selected hypothesis in this way contained subsamples of the true and wrong selected hypotheses of the events.

The subsample of the wrong selected hypothesis is like "background" for our case which must be excluded from the fit. The method of doing it was published in ref.(6).

## 3. Results of partial wave analysis

The partial wave analysis has been done with a 60 MeV step in the $K\pi\pi$-mass range: 1.08 - 1.56 GeV for all targets together.

The $t'$ range was restricted by $t'^*$, where $t'^*$ corresponded to the position of the first diffractive minimum in the $t'$-distributions of events and equaled: 0.04 $(GeV/c)^2$ for Be, 0.03 $(GeV/c)^2$ for Al, 0.02 $(GeV/c)^2$ for Cu, 0.01 $(GeV/c)^2$ for Ag and 0.008 $(GeV/c)^2$ for Pb. The contributions of incoherent events were 20% for Be and fell down to 1.8 for Pb. Then the results discussed here concern mostly the coherent samples (see ref./10/).

The data were fitted using the program PWA of the Illinois Group/7/ modified to the method of the subtraction of a "background" in the likelihood function.

In the frame of the partial wave analysis each partial $K\pi\pi$-state is described by the quantum numbers $J^P LM\eta(n)$, where $J^P$ is the spin and parity of a $K\pi\pi$-system, M is the magnetic substate, $\eta$ is the naturality of the exchange, n denotes the possible isobars in $\pi^-\pi^+$ and $K^-\pi^+$ systems ($K^*$, $\rho$, $\epsilon$, $\kappa$, ...) and L is the orbital angular momentum between an isobar and an odd particle.

The t-channel coordinate system was used in the analysis.

The $K\pi\pi$ mass spectrum displays a broad enhancement in the Q — region and a shoulder in high masses due to the L — meson (see fig.2). The $K^*(890)$ is dominant in the $K^-\pi^+$ mass spectrum and there is a clear $\rho^\circ$

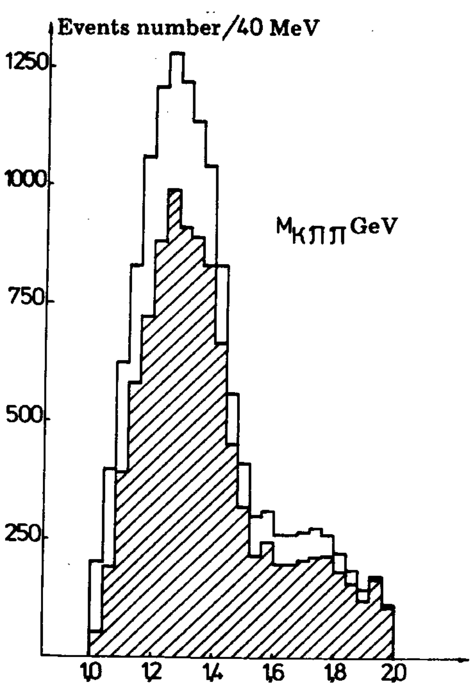


*Fig.2. The $K^-\pi^-\pi^+$ mass spectrum (before and after subtraction of the "background").*

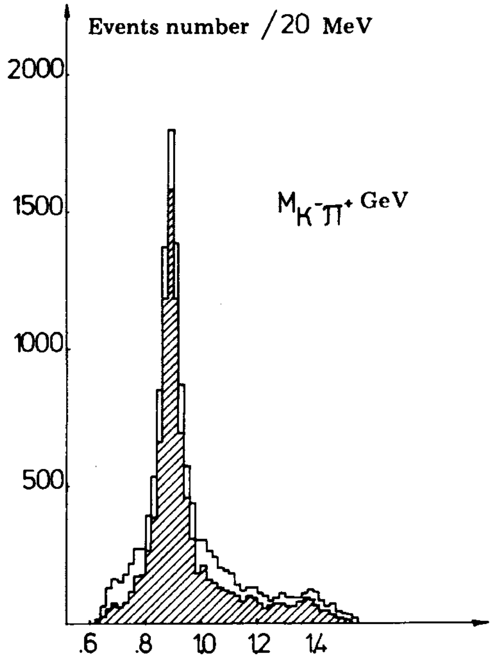


*Fig.3. The $K^-\pi^+$ mass spectrum (before and after subtruction of the "background".*

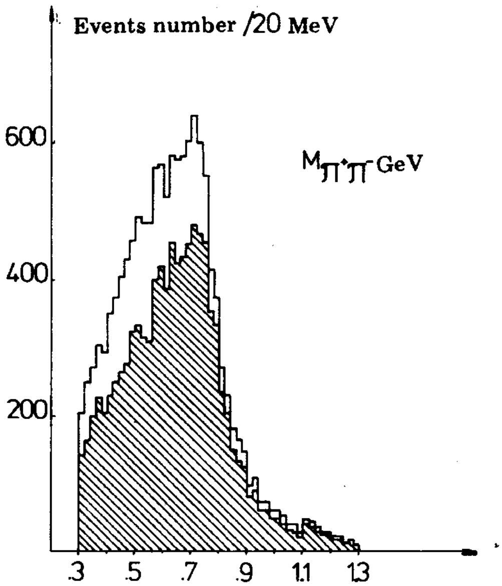


*Fig.4. The $\pi^-\pi^+$ mass spectrum (before and after subtraction of the "background").*

signal in the distribution of the $\pi^-\pi^+$ mass, as is seen in fig.3 and 4.

The amplitudes of the well-known isobars K* and $\rho$ were taken as Breit-Wigner P-wave amplitudes. For the scalar isobar $\epsilon$ in $\pi^-\pi^+$ the S-wave elastic ($\pi\pi$) phase shift parametrization was taken while the S-wave of the $K^-\pi^+$-system $\kappa$ was described as a Breit-Wigner resonance with mass 1.25 GeV and width 600 MeV/3/. The procedure in fitting the $K\pi\pi$ data was in general the same as in fitting the $3\pi$ data discussed in ref./4/. Determining a set of partial waves the nonprincipal waves with contributions less than 3% and a high coherence factor were excluded from the final fit of the data.

The partial waves $0^-S0+(\epsilon K)$ and $0^-S0+(\kappa\pi)$ are not distinguishable. Therefore only one state $0^-S0+(\epsilon K)$ was included in the analysis.

The final set of partial waves is: $0^-S0+(\epsilon K)$, $0^-P0+(K^*\pi)$, $1^+S0+(K^*\pi)$, $1^+S0+(\rho K)$, $1^+P0+(\kappa\pi)$, $1^+P0+(\epsilon K)$. In fig.5-7 the distributions of $1^+S0+(K^*\pi)$ and $1^+S0+(\rho K)$ states and their relative phases over the $K\pi\pi$ mass are shown. In the $1^+S0+(\rho K)$ wave a clear single peak of width ~ 120 MeV is observed at mass ~ 1290 MeV; while in $1^+S0+(K^*\pi)$, a big enhancement at ~ 1230 MeV and a less intensive shoulder at ~ 1400 MeV

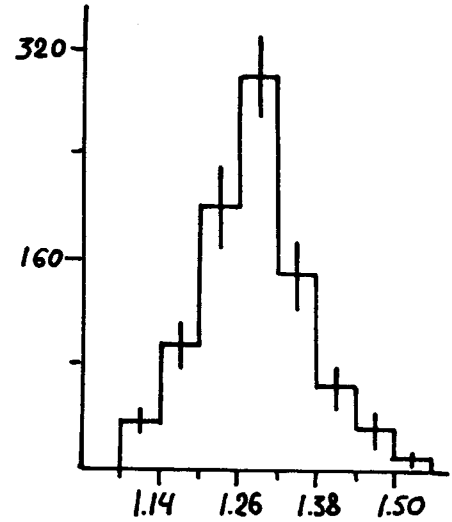


*Fig.5. The intensity of $1^+S0+(\rho K)$ state.*

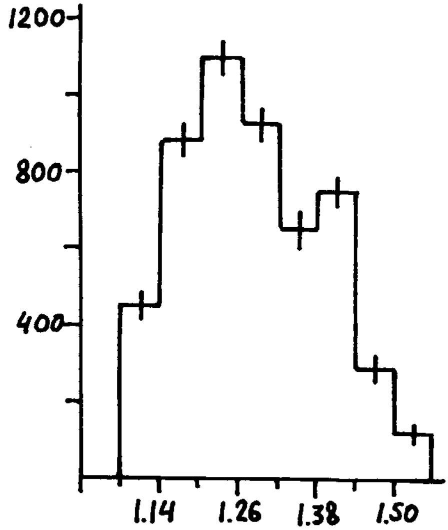


*Fig.6. The intensity of $1^+S0+(K^*\pi)$ state.*

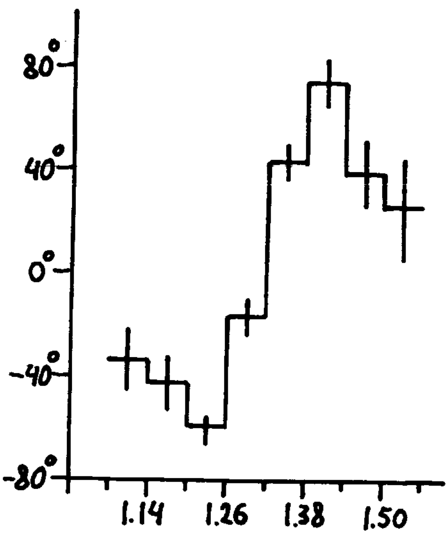


*Fig.7. The phase of $1^+S0+(\rho K)$ with respect to $1^+S0+(K^*\pi)$.*

are seen. The phase of $1^+S0+(\rho K)$ measured relative to $1^+S0+(K^*\pi)$ rapidly rises through ~ 130° in the region of $M_{k\pi\pi}$: 1.2-1.4 GeV and then falls down by ~ 45° at high masses. The manifestation of such properties for these states can be interpreted as resonant and nonresonant ("Deck" background) mechanism of $1^+S0+$ production. The forward phase motion of the $1^+S0+(\rho K)$ implies its resonant properties and predominantly nonresonant $1^+S0+(K^*\pi)$ production with approximately flat own phase in this mass region. The backward motion of the phase and the shoulder in the intensity of $1^+S0+(K^*\pi)$ are expected if this state is resonant and the "Deck" — background mainly contribute to the $(\rho K)$ — channel at these masses. The growth of relative phases of $\kappa\pi$ and $\epsilon K$ P — states by ~ 60° signify that there are other decay channels of the low-mass $1^+$resonance (fig. 8-11).

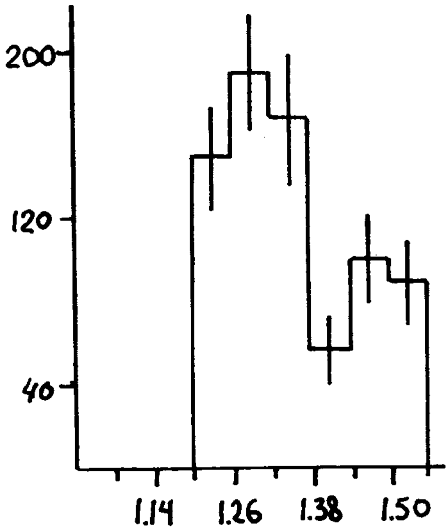


*Fig.8. The intensity of $1^+P0+(\kappa\pi)$ state.*

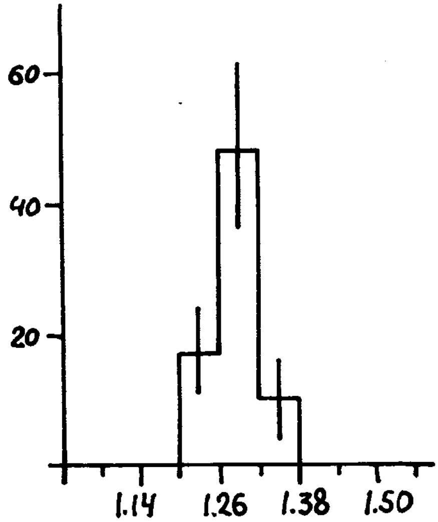


*Fig.9. The intensity of $1^+P0+(\epsilon K)$ state.*

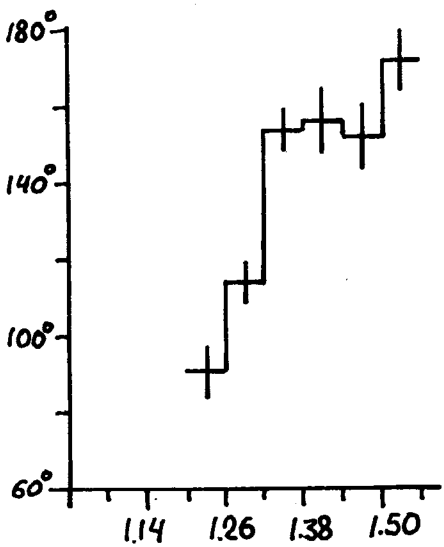


*Fig.10. The phase of $1^+P0+(\kappa\pi)$ with respect to $1^+S0+(K^*\pi)$.*

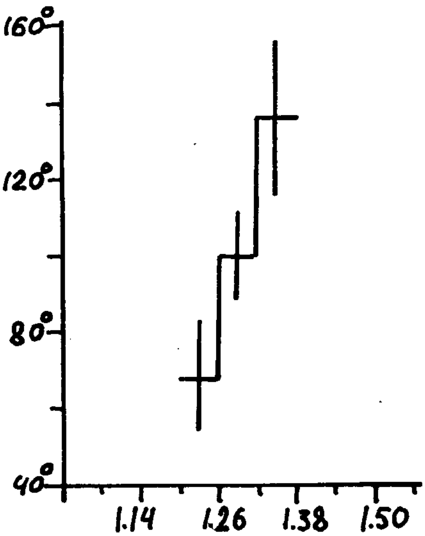


*Fig.11. The phase of $1^+P0+(\epsilon K)$ with respect to $1^+S0+(K^*\pi)$.*

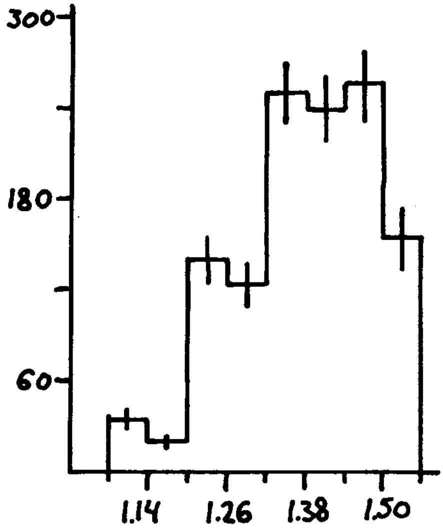


*Fig.12. The intensity of $0^-$S0+(ϵK) state.*

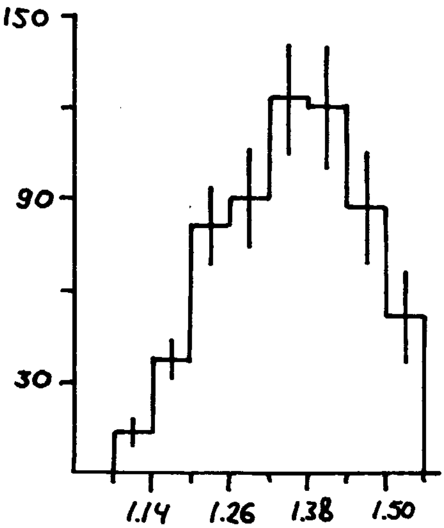


*Fig.13. The intensity of $0^-$P0+(K*π) state.*

For the pseudoscalar states only the $0^-$S0+(ϵK) and $0^-$P0+(K*π) waves were observed. Its intensities presented in fig.12-15 show a broad enhancement at a large Kππ mass. The phases of these states measured with respect to $1^+$S0+(ρK) decrease by ~ 130° in the mass range 1.2-1.38 GeV where $1^+$S0+(ρK) state resonates and rises through ~ 130° and ~ 70° for ϵK and K*π states respectively at ~ 1460 MeV.

These features of $0^-$S0+(ϵK) and $0^-$P0+(K*π) can be explained by a resonant $0^-$-state production at large masses and nonresonant background for lower masses.

It must be emphasized that the total intensity of the $0^-$S0+(ϵK) state is greater than that of $0^-$P0+(K*π) approximately by a factor of two, while for the proton data they are approximately equal. The same correlations between the nuclear and proton data for the S- and P-waves for the $0^-$ state were observed in the diffractive 3π-production[8,9]. This $0^-$ resonance can be interpreted as a radial recurrence of the kaon. It is expected that it is decaying predominantly into ϵK and couple weakly to K*π, while for the proton data its branching ratios are equal for these two channels.

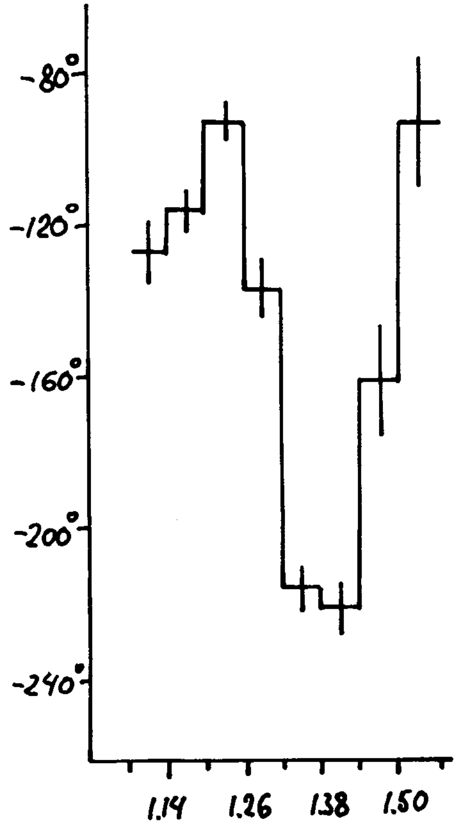


*Fig.14. The phase of $0^-S0+(\epsilon K)$ with respect to $1^+S0+(\rho K)$.*

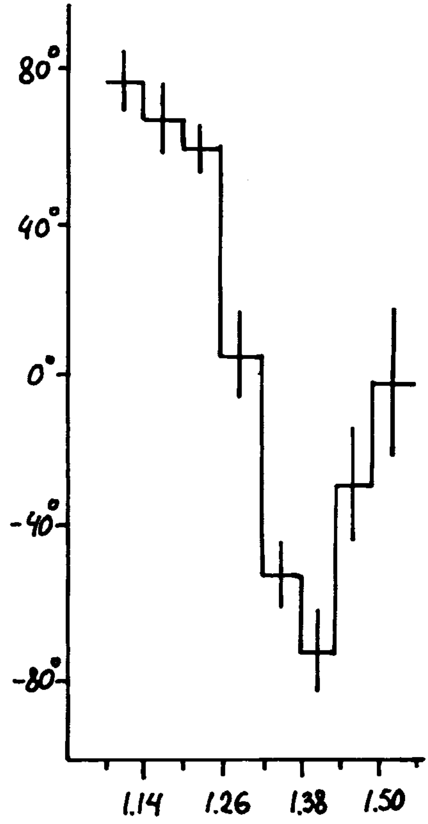


*Fig.15. The phase of $0^-P0+(K^*\pi)$ with respect to $1^+S0+(\rho K)$.*

## 4. Conclusion

From the results of the partial wave analysis of the system coherently produced on nuclei it follows that:

— the properties of the intensities and relative phases of the $1^+$-states indicate that two axial-vector resonances with masses ~ 1300 MeV and ~ 1400 MeV decaying predominantly into $K^*\pi$ and $\rho K$ systems are produced in the reaction,

— the evidence of the radial excited state of the kaon at mass ~ 1460 MeV has been obtained,

— only the unnatural set of states ($0^-$, $1^+$, ...) has been observed in the reaction under investigation, which corresponds to the diffractive exchange mechanism,

— there is strong polarization in the final states due to a negligible contribution of spin-flip amplitudes which indicates helicity conservation in the t-channel.

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