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NEUTRAL KAON REGENERATION ON CARBON IN THE MOMENTUM REGION OF 16—40 GeV/c[1]

V. K. Birulev, F. Deák, V. Genchev, T. S. Grigalaschvilli, B. N. Guskov, J. Hladký, I. M. Ivanchenko, V. D. Kekelidze, D. Kiss, V. G. Krivokhizin, V. V. Kukhtin, M. F. Likhachev, A. L. Ljubimov, I. Manno, E. Nagy*, M. Novak, A. Prokes, H. Ryseck, Yu. I. Salomatin, I. A. Savin, L. V. Silvestrov, V. S. Simonov, G. G. Takhtamyshev, P. Todorov, L. Urban, A. S. Vovenko, G. Vesztergombi.

Preliminary results on the neutral kaon regeneration on carbon obtained at the 70 GeV/c Serpukhov accelerator are presented.

I. INTRODUCTION

The investigation of the energy dependence of the neutral kaon regeneration on different materials[2] has been proposed in 1967. Since the phenomenon of regeneration is due to the fact that $\bar{K}^0$ and K^0 interact with matter in different ways [1, 2], the investigation of the transmission regenerations on hydrogen and deuteron can result in important informations on the energy dependence of the K^0p and K^0n scattering amplitudes and in particular it enables one to check the validity of the Pomeranchuk Theorem [3]. On the other hand, by studying the transmission and diffraction regeneration on complex nuclei one can estimate the electromagnetic size of the neutral kaons.

A part of this experimental program has been completed using the 70 GeV/c Serpukhov accelerator, i.e. a series of measurements was carried out during 1970—1972 on hydrogen[3] [4], deuteron and carbon in the momentum range of 14—50 GeV/c. Here we are reporting on our preliminary results of the experiment designed to study the K^0 regeneration behind a 1 metre carbon regenerator.

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[1] Talk given at the Triangle Meeting on Weak Interactions at SMOLENICE, June 4—6, 1973 by E. Nagy*. This work arose in the collaboration of workers in Dubna, Serpukhov, Budapest, Prague, Berlin, Sofia.

* Central Research Institute of Physics, H-1525, BUDAPEST 114, Hungary.

[2] Okonov E., JINR, Pl — 3788, 1968, Dubna. Vovenko A. S. et al., JINR, 2 — 1 — 5362 Internal Report, 1970, Dubna.

[3] Birulev et al., JINR, El — 6851, 1972, Dubna.

II. THEORETICAL PRELIMINARIES

As it is well known, the intensity of the $\pi^+\pi^-$ decays of the K_L and K_S mesons behind a block of matter placed in the K_L beam is given by

$$\frac{d^2I}{dp\,dt} \sim \varepsilon(p,t)[|\varrho(p)|^2 e^{-t/\tau_S} + |\eta_{+-}|^2 e^{-t/\tau_L} + \tag{1}$$

$$+ 2|\eta_{+-}|\,|\varrho(p)| e^{-\frac{t}{2}[\frac{1}{\tau_S}+\frac{1}{\tau_L}]} \cos(\Delta mt + \Phi_\varrho(p) - \Phi_{+-})],$$

where t is the decay time in the kaon rest frame from the downstream edge of the regenerator: $t = m_K z/pc$, (m_K and p are the kaon mass and momentum, respectively), $\varrho(p) = |\varrho(p)|\, e^{i\Phi_\varrho(p)}$ is the transmission regeneration amplitude, $\eta_{+-} = |\eta_{+-}| e^{i\varphi_{+-}}$ is the ratio of the decay amplitudes: $A(K_L \to \pi^+\pi^-)/A(K_S \to \pi^+\pi^-)$, $\Delta m = m_L - m_S$ and m_L, m_S, τ_L, τ_S are the masses and mean life times of the long- and short-lived kaons, finally $\varepsilon(p, t)$ is the detection efficiency determined by the Monte Carlo method.

The regeneration amplitude can be expressed as a product of three terms: the number of atoms per unit of volume N, the difference of the K^0 and $\bar{K}^0$ forward scattering amplitudes $f_0(p) - \bar{f}_0(p)$, and a term related to the regenerator of the length l:

$$\varrho(p) = \frac{i\pi N}{m_K}(f_0(p) - \bar{f}_0(p)) \frac{1 - \exp[(i\Delta m - 1/2\tau_S) l m_K/p]}{-(i\Delta m - 1/2\tau_S)}. \tag{2}$$

For a very thin regenerator the regeneration phase is given by:

$$\Phi_{if} = \arg i(f_0(p) - \bar{f}_0(p)). \tag{3}$$

In general:

$$\Phi_\varrho(p) = \Phi_{if} + \arg \frac{1 - \exp[(i\Delta m - 1/2\tau_S)\, l m_K/p]}{-(i\Delta m - 1/2\tau_S)} = \Phi_{if}(p) + \Phi_{\Delta m}(p). \tag{4}$$

III. EXPERIMENTAL RESULTS

The experimental set-up was the same as in our previous experiment[3] (Fig. 1). The magnetic spectrometer[4] consists of multiwire spark chambers with magnetostrictive read-out. The triggering signal is provided by scintillation counter logics ($\bar{A}, FI, FII, GI, GII, \bar{A}_L, \bar{A}_R$). A shower detector and an iron

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[4] Basiladze S. G. et al., JINR, Pl — 5361, 1970, Dubna.

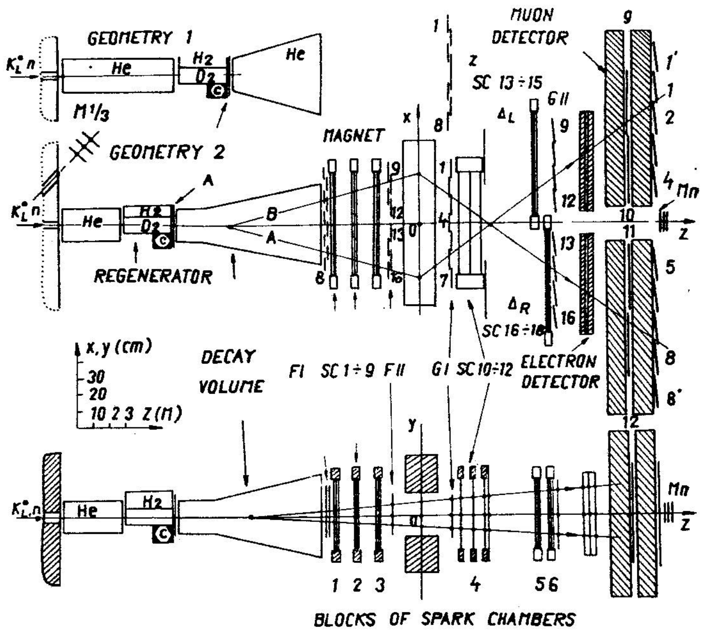

Fig. 1. The layout of the on-line spectrometer.

range telescope serve to separate pions from the electrons and muons produced in the semi-leptonic decay modes.

The charged particle pairs of the decaying K mesons were recorded in the 9 m decay zone required crossing geometry behind the analysing magnet. Our result is based on approximately 2×10^5 triggers. A detailed description of the event reconstruction (program VILLA) can be found in another publication[5]. After the geometrical reconstruction we were left with 90385 events.

Several standard cuts were introduced to enrich the two pion decay content of the sample relative to the three-body decay and the neutron induced interactions in the decay volume. The most important cuts the events have undergone were: $|m_K - m_{\pi\pi}| \leqslant 30$ MeV/c^2, and $\Theta^2 \leqslant 6 \times 10^{-6}$ rad^2, where $m_{\pi\pi}$ is the mass of the charged particle pair under the assumption that they are both pions and Θ is the angle between the vector sum of the momenta of the two decay particles and the known K_L direction. The procedure reduced our sample to 11969 events.

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[5] Vesztergombi G. et al., JINR, P10–7284 Report, 1973, Dubna.

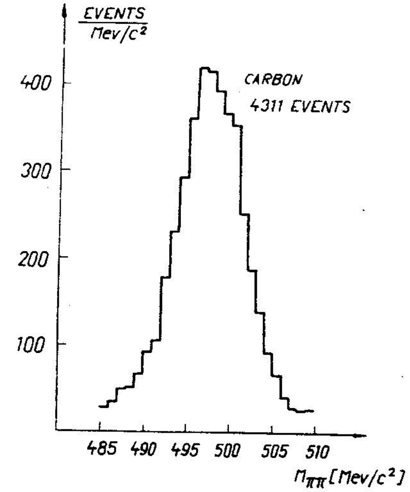

Fig. 2. The invariant mass distribution of the events with $\Theta^2 \leqslant 6$ mrad^2.

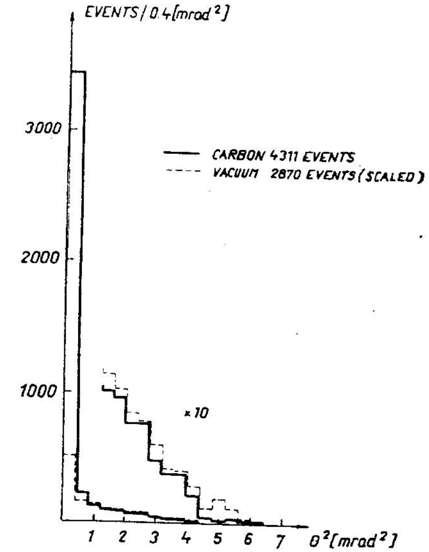

Fig. 3. The angular distribution of the events with 485 MeV/c$^2 \leqslant m_{\pi\pi} \leqslant 510$ MeV/c^2

After a detailed study of the $x-y$ profiles at different z planes as well as other distributions of physical importance, and comparing them with the corresponding Monte Carlo distributions, fiducial volume cuts were applied to the decay vertex and to the charged particle trajectories in the wire chambers, magnet gap and trigger counters. At the same time the electron or muon signatures were also determined for the true $K_{\mu 3}$ and K_{e3} events.

All events surviving the fiducial cuts and a more restricted mass criterion (485 MeV/c$^2 \leqslant m_{\pi\pi} \leqslant 510$ MeV/c^2) with appropriate μ or e flags were recorded on a final DST specially prepared for a maximum likelihood analysis.

The $m_{\pi\pi}$ distribution of the retained 4311 events with double pion signature is shown in Fig. 2. The large peak centred at the kaon mass comes from the $K \to \pi^+\pi^-$ decays above a small and approximately constant background from unidentified decays or interactions. The Θ^2 angular distribution for the same events on a carbon regenerator (Fig. 3) exhibits a sharp transmission regeneration peak comparing with that of a vacuum regeneration. It is remarkable that the background Θ^2 distributions in these two cases are very similar and can be approximated with a linear expression.

Although the transmission regeneration is the overwhelmingly dominating $K \to \pi^+\pi^-$ decay source, the diffraction regeneration can also be observed. In Fig. 4 the invariant mass distribution is shown with a carbon regenerator and without it in the angular range of $0.8 \leqslant \Theta^2 \leqslant 6$ mrad^2, where the trans-

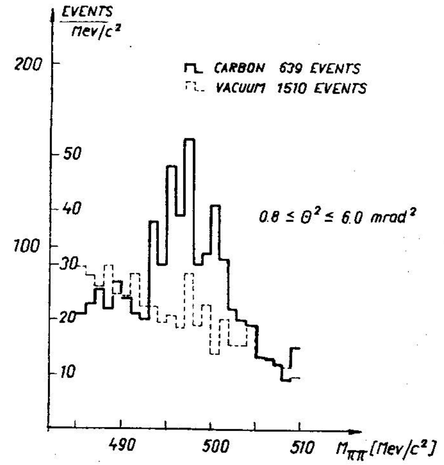

Fig. 4. The invariant mass distribution with a carbon regenerator and without it in the angular range of $0.8 \leqslant \Theta^2 \leqslant 6\,\text{mrad}^2$.

mission regeneration practically does not contribute. The enhancement in the region of the kaon mass is clearly showing the diffraction regeneration on carbon.

IV. FITTING PROCEDURE

Next the experimental data have been divided into proper time bins of $\Delta t = 0.5 \times 10^{-10}$ sec and kaon momentum bins of $\Delta p = 4$ GeV/c, in order to estimate the remaining background. This was carried out by a linear extrapolation in the angular variable Θ^2, its distribution fitting to an expression of the form:

$$N(t, p)\Delta t \Delta p \sim \frac{1}{\Theta_0^2(p)}\, e^{-\Theta^2/\Theta_0^2(p)} + A(t, p) + B(p)\Theta^2. \tag{5}$$

Here the first term represents the transmission regeneration peak broadened to a finite Θ_0 owing to the finite angular resolution of the detector. $A(t, p)$ and $B(p)$, which were determined experimentally, are the background contaminations.

Let us denote by q_i the probability of the i-th event to be observed. This event is specified by t_i, Θ_i, $m_{\pi\pi i}$ and p_i. The probability q_i depends on these quantities as well as on $\Phi = \Phi_{+-} - \Phi_{if}$ and $r = |\varrho(p)/\eta_{+-}|$ through Eqs. (1) to (5).

In order to deduce r and Φ, the goal of this experiment, we applied the maximum likelihood method, where we used as the likelihood function the product

of the probabilities q_i. In other words, instead of dividing our sample of N events into proper time and Θ^2 bins we were looking for the maximum of

$$L = \prod_{i=1}^{N} q_i$$

as a function of $r(p)$ and $\Phi(p)$. Although this latter method is more difficult to apply, the assignment of each event with its own probability of observation uses the maximum information available. Theorefore our method is expected to result in less statistical errors than the classic one, where the events are grouped in finite intervals. Moreover, by means of this method we were able to derive a momentum independent phase, Φ, without any use of the kaon momentum spectrum.

We have performed a number of fits with various sets of parameters. All the time $r(p)$ had the form of a stepwise function, i.e. we assumed a constant r_j ($j = 1, \ldots, 6$) in the j-th momentum bin of $\Delta p = 4$ GeV/c in size. The results are summarized in Table 1. The fits for two and three momentum bins together show that a constant phase assumption is a reasonable one, in accordance with the optical model theory, which predicts only a slight variation

Table 1

	$r = \lvert\varrho/\eta_{+-}\rvert$	$\Phi = \Phi_{+-} - \Phi_{if}$
FIT-1 16 GeV/c $\leqslant p \leqslant$ 24 GeV/c	$r(16-20) = 9.87 \pm 2.18$ $r(20-24) = 9.52 \pm 3.01$	$\Phi(16-24) = 79.2° \pm 21.3°$
FIT-2 24 GeV/c $\leqslant p \leqslant$ 32 GeV/c	$r(24-28) = 9.84 \pm 2.63$ $r(28-32) = 7.72 \pm 1.96$	$\Phi(24-32) = 86.3° \pm 20.1°$
FIT-3 28 GeV/c $\leqslant p \leqslant$ 40 GeV/c	$r(28-32) = 5.78 \pm 2.46$ $r(32-36) = 5.69 \pm 2.55$ $r(36-40) = 6.12 \pm 3.18$	$\Phi(28-40) = 62.5° \pm 27.9°$

Table 2

$\langle p \rangle$ [GeV/c]	$\lvert\varrho/\eta_{+-}\rvert$	$\lvert f - \bar{f}\rvert/k$ [mb]	$\Delta\sigma = \frac{4\pi}{k}\,\text{Im}(f - \bar{f})$ [mb]
18.57	10.05 ± 1.82	2.14 ± 0.39	– 21.2
22.08	9.52 ± 2.38	1.95 ± 0.49	– 19.3
25.97	9.83 ± 2.46	1.96 ± 0.49	– 19.4
29.85	8.15 ± 2.04	1.58 ± 0.40	– 15.7
33.77	8.08 ± 2.46	1.54 ± 0.47	– 15.3
37.82	8.93 ± 3.87	1 68 ± 0 72	– 16 7
Φ (16–40) = 82.6° ± 16.2°			

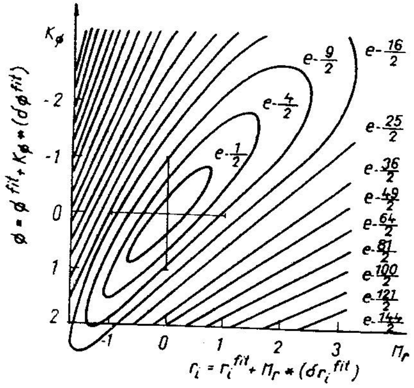

Fig. 5. Likelihood contours at the values $L = L_{max} \exp(-1/2\, n^2)$.

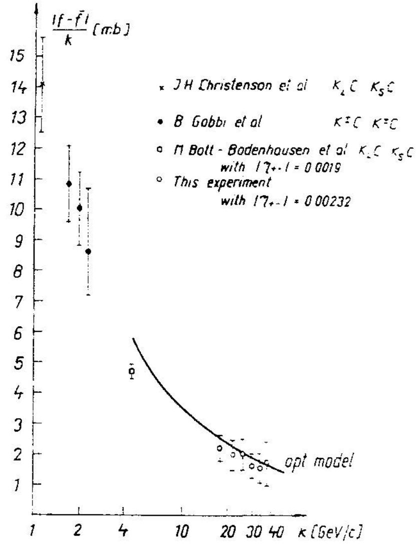

Fig. 6. Experimental results for $|f-\bar{f}|/k$ with K_L and $K^\pm$ mesons, and optical model predictions at high energies.

of the phase in the momentum range of 16—40 GeV/c. In these fits we used $\tau_S = 0.8958 \times 10^{-10}$ sec [5] and $\Delta m = 0.542 \times 10^{10}$ sec^{-1} [6].

In case of the common phase assumption we had a 7 parameter fit (Φ and r_j, $j = 1, \ldots, 6$). In Fig. 5 the corresponding likelihood contours can be seen at the values $\exp(-1/2n) \times L_{max}$ ($n = 0, 1, \ldots$) as a function of K_Φ and M_r, the likelihood function being taken at $\Phi = \Phi^{fit} + K_\Phi \delta\Phi^{fit}$, and $r_i = r_i^{fit} + M_r \delta r_i^{fit}$.

The final results are given in Table 2, with $|\eta_{+-}| = 0.00232$, which is a corrected value of ref. [7] to τ_S of ref. [5] used by us. We express the common phase in a Δm and τ_S dependent form as follows: $\Phi = \Phi_{+-} - \Phi_{if}$ $(16 \leqslant p \leqslant 40) = 82.6° \pm 16.2° + 128° (\Delta m - 0.542 \times 10^{10}\,\text{sec}^{-1})/(0.542 \times 10^{10}\,\text{sec}^{-1}) - 53.6° (\tau_S - 0.8958 \times 10^{-10}\,\text{sec})/(0.8958 \times 10^{-10}\,\text{sec})$. Note that in our fitting procedure Φ is independent of the chosen value of η_{+-}.

In Fig. 6 $2|f_{21}|/k = |f - \bar{f}|/k$ is shown together with the results of earlier measurements on K_L and $K^\pm$ mesons. The data are in good agreement with the optical model calculations.

We have determined the same parameters also by means of the classic method with a kaon momentum spectrum obtained in our previous experiment [4] and the note[3]. The two methods give a reasonable agreement. If in the latter case the likelihood function is approximated with a gaussian one, the corresponding χ^2 turns out to be 53.1 at 51 degrees of freedom.

We have also checked the optical model consistency condition put forward by Goldberg and Telegdi [8]. Although in our case the condition is fulfilled, we are planning a more decisive test in this subject with improved statistics.

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