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THE KAON REGENERATION EXPERIMENT AT SERPUKHOV[1]

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The neutral beam at Serpuchov offers extremely good conditions to carry out experiments with fast electronics in the neutral kaon and neutron physics. Owing to lack of time we intend to outline now only the so called kaon regeneration experiment aimed to determine the difference of the forward scattering amplitude of K^0 and $\bar{K}^0$.

I. BEAM

Fig. 1. shows the channel of the neutral particles produced by the 76 GeV internal proton beam in hitting the Al target. Two collimators seen in the Figure define the beam direction whereas a swiping magnet deflects charged particles. Photons emerging from the Al target are absorbed by a 8 cm thick lead filter before the magnet. The beam at the end of the second collimator contains approximately 10^5 neutral kaons and 10^6 neutrons per internal proton pulses. They arrive at the exit almost uniformly in the time interval of ~ 150 msec,having an average solid angle of 0.5 mrad and a diameter of 3 cm.

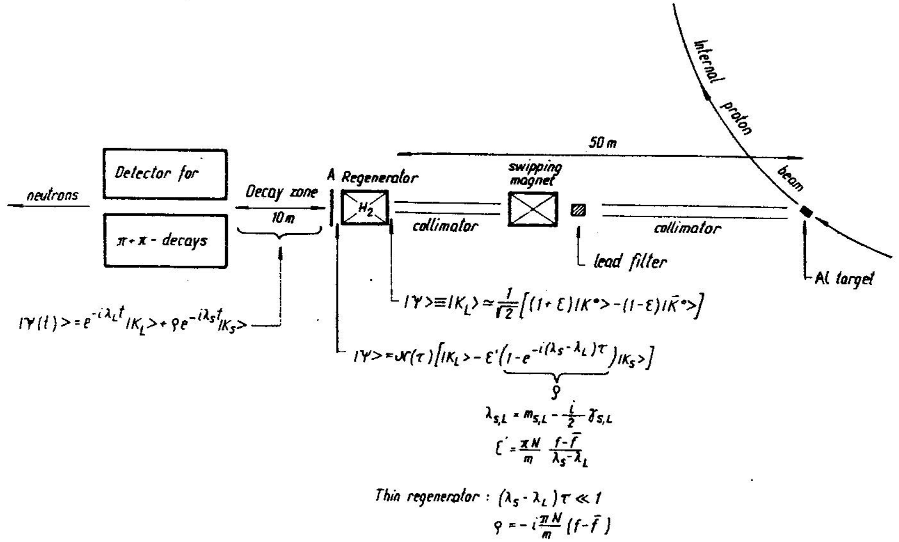

Fig. 1. The experimental layout.

The momentum spectrum of the neutral kaons is shown in Fig. 2. It has a maximum at about 20 GeV with a long tail toward the upper end, which enables one to measure the regeneration amplitude in this experiment up to 40 GeV/c kaon momenta.

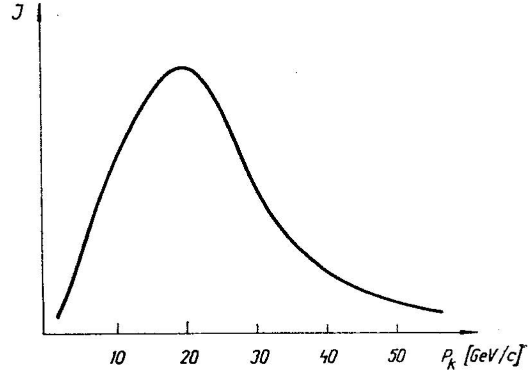

Fig. 2.
The K° momentum spectrum.

II. THE PRINCIPLE OF THE EXPERIMENT

Turning again to Fig. 1. we observe that according to the great difference between lifetimes of the short and long living kaons no K_S meson can be found at the exit of the second collimator. The wave function of the neutral kaon system, having in general two components, according to the short and the long living states consists now only of the second component as indicated in the Figure. The K_L is, in turn, a combination of K° and $\bar{K}^\circ$ as can be seen also in the Figure. We suppose CPT symmetry, but CP violation. The complex number, ε, is a measure of this latter.

Up to the end of the second collimator the beam is travelling in vacuum. (In practice, instead of vacuum He or air is used.) The collimator is, however, followed by matter (liquid hydrogen or some kind of solid states with larger atomic number, depending on the experiment) called regenerator. The regenerator has obviously a great charge asymmetry (it contains no antimatter), hence K° and $\bar{K}^\circ$ interact with it differently. As a consequence, the K° and $\bar{K}^\circ$

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components of the state vector have coefficients at the exit of the regenerator different from those at the entrance, which corresponded to the K_L meson. In other words, whilst a pure K_L beam enters the regenerator, a combination of K_L and K_S emerges at the other end. The ratio, ϱ, of the K_S to the K_L component is called the regeneration amplitude. As we see in the Figure, it depends on two factors, ε' and the one in the bracket, where

$$\lambda_{S,L} = m_{S,L} - \frac{\mathrm{i}}{2}\,\gamma_{S,L}$$

$m_{S,L}$ and $\gamma_{S,L}$ being the masses and inverse lifetimes of the K_S and K_L mesons, respectively, τ is the proper time in the kaon rest system during which the beam passed through the regenerator. ε' contains the physical parameters to be investigated, namely $f - f'$, the difference of the forward scattering amplitudes of the K° and $\bar{K}^\circ$. In the expression for ε' N and m are the Avogadro number and the neutral kaon mass.

The factor $N(\tau)$ accounts for the total absorption of the beam in the regenerator due to the different interactions of kaons with matter. Since it is only a common normalization factor, it can be omitted in the following.

Note that in case of a thin regenerator, i. e. when

$$(\lambda_S - \lambda_L)\tau \ll 1$$

ϱ is linearly related to $f - \bar{f}$.

The regenerator is followed immediately by an anticounter that veto all charged particles produced in the regenerator. Thus only neutrons and neutral kaons, having state vectors as indicated, can pass through. Neutrons leave the decay zone and the detector through a channel created for this purpose. On the other hand, a fraction of the kaons decays in the decay base. Therefore, along the decay base the kaon wave function has the form as written in Fig. 1, t being the proper time in the kaon rest system. We see that this function coincides with that at the veto counter at $t = 0$.

The regeneration amplitude, ϱ, the aim of the experiment, can be determined in the following way. Let us consider a particular decay mode of the neutral kaons, say the $\pi^+\pi^-$ decay mode, which is relatively easy to detect. The probability amplitude, A, standing for that the kaon is decaying in this channel between proper times t and $t + \Delta t$ is equal to the expression written in Fig. 3. Here H is the Hamiltonian of the transition. $\langle\pi^+\pi^-|H|K_S\rangle$ and $\langle\pi^+\pi^-|H|K_L\rangle$ are the amplitudes for the corresponding transitions. Note that the latter violates CP symmetry, because both $\pi^+\pi^-$ and K_L are CP eigenstates having, however, different eigenvalues.

The probability $N(\pi^+\pi^-)$ of the transition in question, which is proportional to the detected number of the $\pi^+\pi^-$ decays, is equal to the square of the amplitude, seen also in the Figure, where η_{+-} is the ratio of the CP violating to CP conserving amplitudes, Φ_{+-} is its phase, Δm is the mass difference and Φ_ϱ is the phase of the regeneration amplitude, which, in turn, is related to $f - \bar{f}$ as indicated, in case of a thin regenerator. The transition probability as a function of the time, t, is shown also in the Figure. A clear minimum followed by a maximum can be distinguished. which is due to the interference between the CP violating $K_L \to \pi^+\pi^-$ and regenerated $K_S \to \pi^+\pi^-$ decay amplitudes. After having counted in each proper time interval the observed $\pi^+\pi^-$ decays a fit to this theoretical curve can be performed, which yields an estimation of $|\varrho|$ and Φ_ϱ since the complex η_{+-} and real Δm are known with enough precision in low energy measurements. There is also a good indication that they do not depend on the kaon momenta.

$$A = \langle\pi^+\pi^-|H|\Psi(t)\rangle = \langle\pi^+\pi^-|H|K_L\rangle e^{-i\lambda_L t} + \varrho\,\langle\pi^+\pi^-|H|K_S\rangle e^{-i\lambda_S t}$$

$$N(\pi^+\pi^-) \equiv |\langle\pi^+\pi^-|H|\Psi(t)\rangle|^2 \propto |\varrho|^2 e^{-\gamma_S t} + |\eta_{+-}|^2 e^{-\gamma_L t} + 2|\varrho||\eta_{+-}| e^{-\frac{\gamma_S+\gamma_L}{2}} \cos(\Delta m t + \phi_\varrho - \phi_{+-})$$

$$\eta_{+-} = \frac{\langle\pi^+\pi^-|H|K_L\rangle}{\langle\pi^+\pi^-|H|K_S\rangle}\,; \qquad \phi_{+-} = \arg(\eta_{+-})$$

$$\Delta m = m_L - m_S\,; \qquad \phi_\varrho = \arg(\varrho) \approx \arg(f - \bar{f})$$

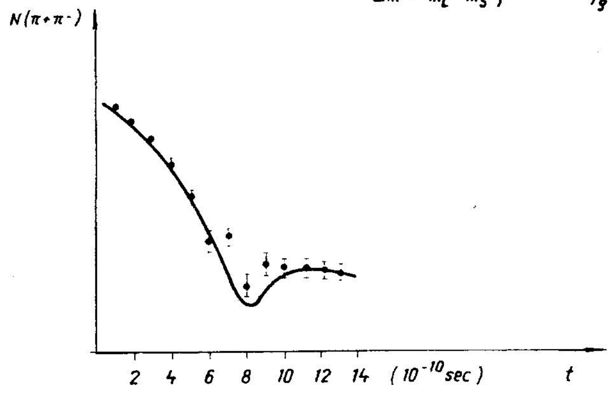

Fig. 3. The probability of $K \to \pi^+\,\pi^-$ decay as a function of the time elapsed in the K° rest frame. „Experimental data" are shown only for illustration.

III. THE $\pi^+\,\pi^-$ DETECTOR

Fig. 4 shows the detector of the π^+ and π^- produced in the kaon decay. It consists of a system of wire spark chambers and a magnet of 12 kG in strength, inbetween. There is also a system of hodoscopes which triggers the chambers when charged particles in the required configuration pass through them. The chosen geometry strongly supresses the detection of the two charged pions from the $K_L \rightarrow \pi^+\pi^-\pi^0$ decay mode. Moreover, behind the last chambers an iron wall is placed which can be penetrated only by muons. Therefore, by means of the counters following the iron wall one can select the $K_{\mu 3}$ background as well. The remaining background arises from K_{e3} events, which can be eliminated using the so called electron detectors (Čerenkov counters or ionization calorimeters) in the place indicated in the Figure.

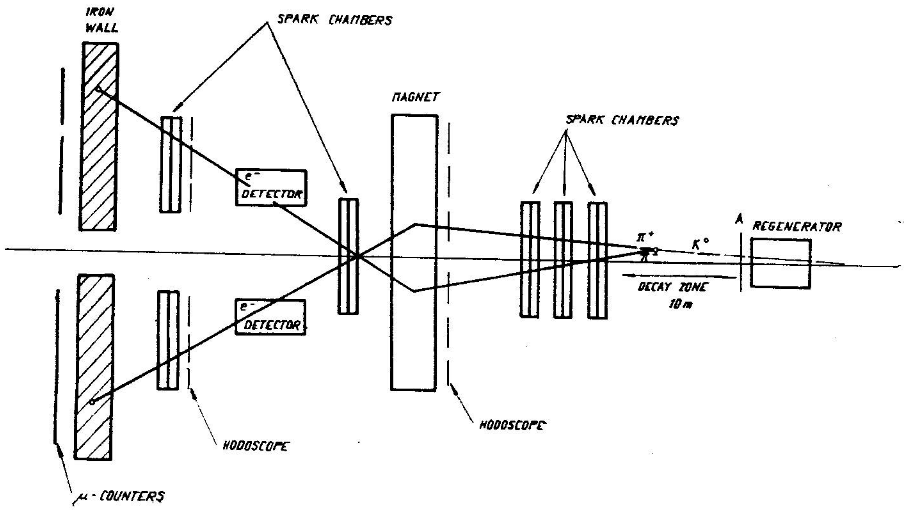

Fig. 4. The $\pi^+\pi^-$ detector.

We have, of course, an additional possibility to select $\pi^+\pi^-$ decays, namely by means of kinematical reconstruction. The coordinates of the sparks are registrated on-line on magnetic tapes and an off-line geometrical reconstruction program calculates the resultant invariant mass and direction of the positive and negative tracks, assuming that both of them are pions. The true $\pi^+\pi^-$ events must give invariant masses near 498 MeV, the kaon mass, and the resultant direction to the average beam direction must not exceed 1 mrad, the maximum divergence of the beam, because we are interested in the so-called transmission regeneration connected with *forward* scattering of the kaons.

IV. THEORETICAL IMPLICATIONS

What is the significance of this experiment from the theoretical point of view? We have many theories that predict the bahaviour of the forward scattering amplitude of hadrons at high energies. The most important predictions, e. g. the Pomeranchuk theorem, are connected with the behaviour of the *difference* between particle-antiparticle scattering amplitudes. This experiment measures this difference in case of the neutral kaons *in the most simple way*. Experiments with similar purpose have already been carried out at Serpukhov. We have results on the total cross sections of negative particles, such as $\overline{p}$, π^-, K^- on protons. At this time there is no possibility to obtain similar quantities directly for positive particles, thus there is no possibility to measure the above mentioned differences. One must wait for the realization of the external proton beam. But even in this case, the difference of total cross sections of positive and negative particles could be obtained in *two* independent measurements, their errors then will have to be summed up. The main advantage of the kaon regeneration experiment lies in that it gives directly the difference of the forward scattering amplitudes between particles and antiparticles in one measurement.

The experiment is now in progress at Serpukhov, some preliminary results are expected for the autumn of this year.

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