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Collaboration HYPERON

STUDY OF *K*-MESON DECAYS WITH THE **HYPERON-2** SPECTROMETER (PROPOSAL OF THE EXPERIMENT)

1998

V.Yu.Batusov, J.A.Budagov, I.E.Chirikov-Zorin, Yu.I.Davydov, V.P.Dzhelepov, V.B.Flyagin, V.V.Glagolev, A.V.Kolomyichenko, Yu.F.Lomakin, S.N.Malyukov, O.E.Pukhov, V.I.Romanovsky, N.A.Russakovich, N.L.Russakovich, A.A.Semenov, A.N.Shalyugin, A.S.Soloviev, I.A.Suslov, V.B.Vinogradov, A.G.Volodko

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IHEP, Tbilisi

1 Introduction

The main goal of the proposal is to upgrade the existing set-up HYPERON-2 and to fulfil new investigation of K-meson decays. The experiment (SERPUKHOV-167 by the international classification) is in progress and the last data taking was in 1997.

Some new results were obtained [1, 2, 3, 4] with the HYPERON-2 spectrometer. We made the best estimation of the upper limit $Br(K_S^0 \to e^+e^-) \leq 2.8 \cdot 10^{-6}$ and the most precise measurement of the K_{e3} decay form factors. These results are included in the Review of Particle Properties (RPP). The measured parameters of the matrix elements of the $K^+ \to \pi^+\pi^0\pi^0$ decay are also the most precise ones.

The project aims to study radiative and some other K decays with neutral products using a positive 10 GeV/c beam at the Serpukhov PS. These decays are rarer and more difficult to study than the decays which were studied with HYPERON-2 previously.

One of the main tasks is to search for and to study the structure-dependent (SD) part of photon emission in semi-leptonic and nonleptonic K decays:

$$K^+ \to \pi^+\pi^0\gamma, \quad K^+ \to \pi^0 e^+\nu\gamma.$$

The SD contribution is of special interest: it contains information on the quark structure of hadrons and dynamics of quark–quark interaction. Thus, the experimental study of radiative kaon decays is an important way for the verification of different models developed in the framework of the effective chiral Lagrangian approach to description of low energy meson processes, which is widely used.

The form factors of the decays

$$K^+ \to \pi^0 e^+\nu, \quad K^+ \to \pi^0\pi^0 e^+\nu$$

are also of large theoretical interest.

The present experimental status of these decays is not satisfactory. There are a few successful experimental attempts to search for direct photon emission (DE) in the $K^+ \to \pi^+\pi^0\gamma$ mode. However, the world average still has a large error. No SD emission was found in the reaction $K^+ \to \pi^0 e^+\nu\gamma$ because of statistics and background subtraction problems. The world statistics of the $K^+ \to \pi^0\pi^0 e^+\nu$ decay numbers only 35 events; the precision of the decay width and the form factor is low. In the last experiment [1] on the K_{e3} decay nonzero scalar and tensor form factors were obtained, which points to possible existence of "beyond-the-Standard-model" effects. Checking of this result is of large interest.

Unlike the case in previous experiments, our spectrometer allows measurement of all kinematic parameters: momenta of incoming and secondary charged particles, energies and emission angles of secondary γ-quanta. Thus, our advantages, as we expect, are better separation from the background (more constrained fit) and smaller systematic uncertainties than in previous experiments.

During three years we intend to collect new data in 2-3 runs and to process a major part of the statistics.

Comment. There is another experiment under way at the Serpukhov PS, Serp-166, devoted to pion and kaon decays. The set-up is situated in a negative unseparated beam about 40 GeV/c (spokesman V.Bolotov). That experiment concentrates on rare decays. However, both groups mean to get statistics in the field of this project and the groups decided that it is quite essential to compare results of the experiments with different set-ups and trigger conditions. Other related Experiments, BNL-787, BNL-865 and others, are aimed to study quite rare decays. KEK-304 was taking data on the $K^+ \to \pi^0 e^+ \nu$ decay in 1996 (there is not yet more information about this experiment) and E927 at BNL proposed to measure this reaction too.

Specific goals

The experimental set-up allows us to measure or evaluate parameters of the following decays at Pbeam = 10 GeV/c (PLab):

$$\begin{array}{cc}
K^+ \to \pi^+\pi^0\pi^0 & K^0_S \to e^+e^- \\
\underline{K^+ \to \pi^+\pi^0\gamma} & \\
K^+ \to \pi^+\gamma\gamma & K^0_S \to \gamma\gamma \\
\underline{K^+ \to \pi^0 e^+\nu} & \\
K^+ \to \pi^0\pi^0 e^+\nu & K^0_S \to e^+e^-\gamma \\
\underline{K^+ \to \pi^0 e^+\nu\gamma} & K^0_S \to \pi^0 e^- e^+
\end{array}$$

where K^0-mesons are produced by K^+ charge exchange reactions on a nuclear target. The underlined reactions are the main objectives of this project. Data containing all K^+-decay modes can be collected during the same data taking.

2 Background and significance

2.1 Radiative decay $K^+ \to \pi^+\pi^0\gamma$

The main goal of this decay study is measurement of the direct emission (DE) part of the decay amplitude. The DE part contains information about hadron structure because it describes the direct transition to $\pi\pi\gamma$ state. It is important that internal bremsstrahlung is suppressed in this decay by the $|\Delta I| = 1/2$ rule. Thus the DE contribution is relatively large and can be measured more easy than in other radiative decays. The DE part of the amplitude is mainly determind by chiral anomalies which play an important role in low energy physics.

Unfortunately, according to latest theoretical estimations [5] the CP violating term is strongly suppressed compared with the DE term (about three orders of magnitude). Nevertheless, final conclusion should be stated by an experiment.

There are some successful experimental attempts [6, 7, 8] in searching for the DE-contribution. In our opinion the world average $Br(DE) = (1.8 \pm 0.4) \cdot 10^{-5}$ still has a large error to compare with the latest theoretical calculations (interference included) $Br(DE) = 2.23 \cdot 10^{-5}$ [5]. We expect to increase statistics significantly (by a factor of about 10, see Table 1).

To avoid ambiguity it is also very important to measure all accessible kinematical parameters of the reactions.The last result for $K_{\pi\pi\gamma}$ branching ratio [6] was obtained using set-up which allowed to measure charged particle track angles and photon energies. In the other two experiments [7, 8] photon energies were not measured. With our set-up we can measure all kinematical parameters: momenta of charge particles, emission angles and energies of photons and expect better background separation (more constrained fit) and smaller systematic errors.

2.2 Radiative decay $K^+ \to \pi^0 e^+ \nu\gamma$

Decays $K^+ \to \pi^0 l^+ \nu_l \gamma$ are electroweek ones with γ-radiation produced by inner bremsstrahlung and structure radiation from intermediate states of K meson. The last one is the most interesting because it contains information on internal K-meson structure. Relative probability of the decay:

$$Br = Br_{IB} + Br_{SD} + Br_{INT}$$

contains the inner bremsstrahlung term (IB), structure dependent term (SD) and their interference (INT).

The IB contribution can be calculated in the QED [9, 10] frames. Two other terms SD and INT depend on the vector and axial-vector form factors (f_V and f_A) of the structure radiation. They were evaluated in [9] on the base of current algebra and PCAC hypotesis and in [11] using the effective chiral lagrangian approach. According to these theoretical estimations the structure dependent term is about 1 2% of the IB term.

The $K^+ \to \pi^0 e^+ \nu\gamma$ decay was studied in four experiments [12, 13, 14, 15]. Results [12, 14, 15] were done with the bubble chamber technique. In [12, 14] 16 and 13 events were found. The Br_{IB} measured is in accordance with the QED calculations. In [13, 15] 192 and 88 events were found and all three terms of radiation components were estimated, in particular, SD-INT emission: $Br_{SD} < 5.31 \cdot 10^{-5}$ and $Br_{SD+INT} < 9.5 \cdot 10^{-5}$.

Measurement of the SD-part of the decay probability should be done in new experiments on the $K^+ \to \pi^0 e^+ \nu\gamma$ decay with higher statistics. Such measurement gives possibility to verify theoretical models.

2.3 Semileptonic $K^+ \to \pi^0 e^+ \nu$ decay

The $K^+ \to \pi^0 e^+ \nu$ decay or K_{e3} is well described by the matrix element M proportional to only one form factor:

$$f_+(q^2) = f_+(0) \cdot (1 + \lambda_+ q^2/m_\pi^2),$$

where q is four-momentum transfer to dilepton system and λ - free parameter.

This decay was studied in many experiments including one performed by the authors of the project. Our result [1] is the most precise estimation of λ_+. However, the situation is not so simple. The most general form of the decay matrix element, which includes the scalar f_S and tensor f_T form factors, was fitted to the experimental data [1] and nonzero values for f_s and f_T were obtained. They are 3 4 standard deviations larger than zero. This fact points to possible existence of effects "beyond the Standard Model". There is at least one theoretical model [16], inserting tensor interaction in the standard decay amplitude, which describes the experimental results.

Thus, it seems very important to test this result in new precise experiments on $K^+ \to \pi^0 e^+ \nu$ decay. The project means to obtain an event sample with better positron identification and higher statistics than in previous experiments.

2.4 Semileptonic $K^+ \to \pi^0 \pi^0 e^+ \nu$ decay (K_{e4})

Matrix element for K_{l4} decays generally can be described by four form factors:

$$M \propto \bar{\psi}_\nu (1-\gamma_5)[\frac{f_1}{m_K} R_\rho + fracf_2 m_K Q_\rho + fracf_3 m_K K_\rho \\ +i\frac{f_4}{m_K} \epsilon_r ho^{\alpha\beta\gamma} R_\alpha Q_\beta K_\gamma]\gamma^\rho \psi_l,$$

where $R = P_{\pi_1^0} + P_{\pi_2^0}$, $Q = Q_{\pi_1^0} - Q_{\pi_2^0}$, $K = P_l + P_\nu$ and form factors f_i (i=1,2,3,4) are as a rule functions of invariants $P_{\pi_1^0} + P_{\pi_2^0}$, $P_{\pi_1^0} + P_K$ and $P_K + P_{\pi_2^0}$.

It was shown in reference [17] that it is possible to evaluate all form factors for K_{l4} decays using PCAC hypothesis and neglecting $\pi\pi$-interaction. The result is in good agreement with experiments on the $K^+ \to \pi^+ \pi^- e^+ \nu$ decay. We propose to study the $K^+ \to \pi^0 \pi^0 e^+ \nu$ decay which is described by only one form factor because of two π^0's identity and small positron mass. In [13] one can see that the theoretical models discribe this reaction rather poorly. Consequently, experiment on measurement of the form factor of the $K^+ \to \pi^0 \pi^0 e^+ \nu$ decay is a good independent test of theoretical models and $|\Delta I| = 1/2$ rule.

The $K^+ \to \pi^0 \pi^0 e^+ \nu$ decay was investigated in only three experiments [12, 13, 18]. Freon bubble chambers were used in [12, 18] and 2 and 10 events were found. In electronic experiment with e/m-calorimeters [13] were fixed 25 events. We think investigation of this decay is a very important task. We intend to obtain higher statistics on this decay than in previous experiments with better event identification.

3 Research design and method

As one can see above the experimental set-up already exists and proved to be reliable in number of experiments. It was reconstructed and updated [3] for the kaon decays.

It consists of beam facilities (figure 1), two magnetic spectrometer arrangements, two electromagnetic (e/m) calorimeters and is able to measure momenta of charged particles and γ-quanta energies and impact points. There are also some scintillation counters and two hodoscopes for a trigger purpose.

We use the unseparated secondary beam of 10 GeV/c positive particles from the U-70 accelerator. The total beam intensity is about 10^6 particles per spill. The contamination of K mesons in the beam is about 7% and K mesons are picked out by the threshold gas Cherenkov counters Č1 Č3.

The momentum spread in the beam is about 1.5% but we can mesure it more precisely ($\Delta p/p = 0.5\%$) with the beam spectrometer based on the analysing magnet MAGNET1 with a very uniform field ($\Delta H/H \leq 0.1\%$) and a set of 2mm multiwire proportional chambers PC1 PC4. The scintillation counters S1 S4 are used for counting kaons entering the two-meter decay region between the chambers PC4 and PC5. The scintillation counter A with a hole in the center is in anticoincidence to suppress K decays in the beam spectrometer area at the trigger level.

Secondary charged particles are registered in the secondary spectrometer by the magnet MAGNET2 and a set of 2-mm proportional chambers PC5 PC8. The reconstructed momentum range is $1.5 \div 10 GeV/c$ and the relative momentum resolution over this region is $1 \div 3\%$.

γ quanta from K^+ and π^0 decays are registered by two electromagnetic calorimeters EMC1 and EMC2. Both detectors are lead glass Cherenkov hodoscope calorimeters. They are matrix of 19×15 cells (EMC1) and 24×24 cells (EMC2). The cell sizes are $100 \times 100 mm^2$ in EMC1 and $85 \times 85 mm^2$ in EMC2. The central zone of EMC2 consists of smaller cells $42.5 \times 42.5 mm^2$. To let forward photons and charged particles pass through the spectrometer, EMC1 has a $50 \times 50 cm^2$ hole in the center. The energy resolutions are $\simeq 0.1/\sqrt{E}$ for EMC1 and $\simeq 0.08/\sqrt{E}$ for EMC2. γ-quanta impact positions are reconstructed from the shower energy distribution in the calorimeter cells. The mean reconstruction accuracies are $\Delta x \simeq \Delta y \simeq 9mm$ in EMC1 and $\Delta x \simeq \Delta y \simeq 7mm$ and $\Delta x \simeq \Delta y \simeq 4.5mm$ in EMC2 for cell sizes $85mm$ and $42.5mm$ respectively. Two scintillation hodoscopes HX and HY are used to increase the track reconstruction efficiency.

The specific feature of our trigger is a requirement that the number of detected gammas $N_\gamma \geq 3$ in both calorimeters. To determine N_γ at the trigger level all cells in EMC2 are united into 5 groups and EMC1 is included as one group. Energies in at least three groups of cells must be above a definite threshold (adjustable). The trigger formula is

$$Tr = S1 \cdot S2 \cdot S3 \cdot S4 \cdot \bar{A} \cdot \bar{\check{C}}1 \cdot \check{C}2 \cdot \bar{\check{C}}3(\geq 3groups).$$

These requirements suppress an incident beam to the level of 10^{-4} leaving events with above mentioned decays plus some admixture of background. That is, all decay modes under investigatiuon are taken simultaneously. We intent also to get a sample of the events with the requirement on $N_\gamma \geq 1$.

The data acquisition system (DAQ) is based on two IBM PC computers. DAQ electronics has two CAMAC type branches with special controllers for MWPC's and EMC's. The system allows to test all detector efficiencies and stability by on-line control programs.

Calibrating the e/m-calorimeters can be done in three ways:

1. each EMC1 element is exposed to the positron beam of definite energy which can be set within $3 \div 10 GeV$ interval. The same procedure can be done with the EMC2 but only for the central elements;

2. having target placed in the beam we process events with gammas and using fitting procedure for ADC energy scales reconstruct π^0 and η meson masses;

3. the $K^+ \to \pi^+\pi^0$ decay which is not completely suppressed by the trigger gives us a very good possibility of calibrating the e/m-calorimeters with tagged π^0. The calibration was done by fitting two γ-quanta effective mass to the π^0 mass.

As it is already clear we developed a set of off-line programs for event reconstruction and Monte-Carlo simulation which can be easily adapted to any data processing requirements.

To this moment we have had some runs for the project aim with about 10^7 row events recorded on tapes which we process now before a new exposition.

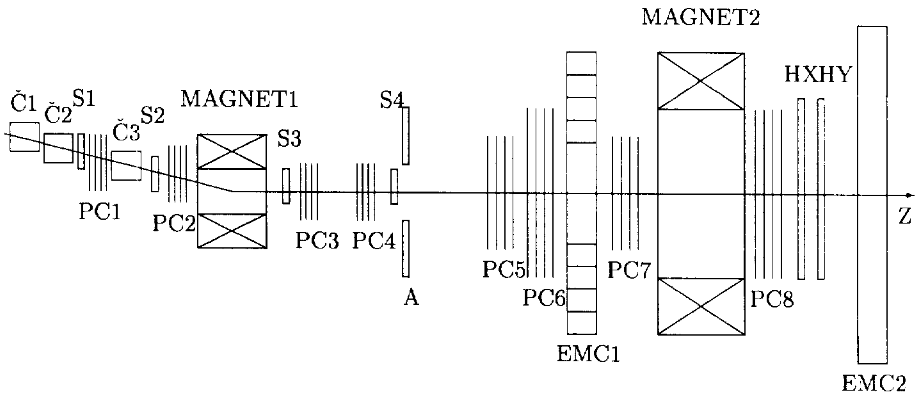

Figure 1: Layout of the HYPERON-2 spectrometer

Table 1: Expected statistics

K^+-decay	Expected number of events (reconstr.)	World statistics (or best experiment)	Physics
$\pi^+\pi^0\gamma$	$2 \cdot 10^4$	$2.7 \cdot 10^3$	Br(DE), CP?
$\pi^0 e^+\nu\gamma$	$2 \cdot 10^3$	189	Def. or limit Br(SD)
$\pi^0 e^+\nu$	$6 \cdot 10^4$	$3.2 \cdot 10^4$	Chiral Lagrangians, tensor interaction?
$\pi^0\pi^0 e^+\nu$	200	25	Chiral Lagrangians, $\lvert\Delta I\rvert = 1/2$ rule

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Сотрудничество ГИПЕРОН: Батусов В.Ю. и др. E1-98-193
Исследование распадов K-мезонов на спектрометре ГИПЕРОН-2
(Предложение эксперимента)

Главной целью проекта является проведение новых исследований некоторых радиационных распадов K^+-мезонов, распадов $K^+ \to \pi^0 e^+ \nu$ и $K^+ \to \pi^0 \pi^0 e^+ \nu$ на большей статистике. Набор детекторов установки ГИПЕРОН-2, в отличие от предыдущих экспериментов, позволяет измерять все доступные кинематические параметры продуктов распадов.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 1998

Collaboration HYPERON: Batusov V.Yu. et al. E1-98-193
Study of K-Meson Decays with the HYPERON-2 Spectrometer
(Proposal of the Experiment)

The main goal of the proposal is to fulfil new investigation of some radiative K^+-meson decays, the $K^+ \to \pi^0 e^+ \nu$ and $K^+ \to \pi^0 \pi^0 e^+ \nu$ decays on the basis of high statistics. Unlike the case in previous experiments, the HYPERON-2 set-up allows measurements of all available parameters of the decays products.

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

Communication of the Joint Institute for Nuclear Research. Dubna, 1998

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