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**$K_{e3}$  decay studies in OKA experiment**

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## Abstract

Yushchenko O.P. et al.  $K_{e3}$  decay studies in OKA experiment: NRC «Kurchatov institute» – IHEP Preprint 2017-2. – Protvino, 2017. – p. 5, figs. 3, tables 1, refs.: 11.

Recent results from OKA setup concerning form factor studies in  $K_{e3}$  decay are presented. About 5.25M events are selected for the analysis. The linear and quadratic slopes for the decay formfactor  $f_+(t)$  are measured:  $\lambda'_+ = (26.1 \pm 0.35 \pm 0.28) \times 10^{-3}$ ,  $\lambda''_+ = (1.91 \pm 0.19 \pm 0.14) \times 10^{-3}$ . The scalar and tensor contributions are compatible with zero. Several alternative parametrizations are tried: the Pole fit parameter is found to be  $M_V = 891 \pm 2.0$  MeV ; the parameter of the Dispersive parametrization is measured to be  $\Lambda_+ = (24.58 \pm 0.18) \times 10^{-3}$ . The presented results are considered as preliminary.

## Аннотация

Ющенко О.П. и др. Исследования  $K_{e3}$  распада в эксперименте ОКА: Препринт НИЦ «Курчатовский институт» – ИФВЭ 2017-2. – Протвино, 2017. – 5 с., 3 рис., 1 табл., библиогр.: 11.

Представлены новые результаты исследования  $K_{e3}$  распада, осуществленные на установке ОКА. В анализе использованы около 5.2M событий. Измеряемые линейный и квадратичный параметры наклона формфактора  $f_+(t)$ :  $\lambda'_+ = (26.1 \pm 0.35 \pm 0.28) \times 10^{-3}$ ,  $\lambda''_+ = (1.91 \pm 0.19 \pm 0.14) \times 10^{-3}$ . Вклады скалярного и тензорного членов сравнимы с нулем. Использовались несколько альтернативных параметризаций: параметр полюсного фита  $M_V = 891 \pm 2.0$  MeV; параметр дисперсионной параметризации  $\Lambda_+ = (24.58 \pm 0.18) \times 10^{-3}$ . Представленные результаты являются предварительными.

## Introduction

The kaon decays provide unique information about the dynamics of the strong interactions. It has been a testing ground for such theories as current algebra, PCAC, Chiral Perturbation Theory (ChPT) etc. Another direction is a search for new interactions, such as tensor and scalar ones. Here, we present a high-statistics study of  $K_{e3}$  decays from OKA detector at U-70 Proton Synchrotron.

### 1. OKA beam and detector

OKA is the abbreviation for 'Experiments with Kaons '. OKA beam is a RF-separated secondary beam of U-70 Proton Synchrotron of IHEP, Protvino. The beam is described elsewhere [1]. RF-separation with Panofsky scheme is realised. It uses two superconductive Karlsruhe-CERN SC RF deflectors [2], donated by CERN. Sophisticated cryogenic system, built at IHEP [3] provides superfluid He for cavities cooling. The resulting beam has up to  $\sim 20\%$  of kaons with an intensity of  $\sim 10^6$  kaons per 3 sec U-70 spill. The OKA

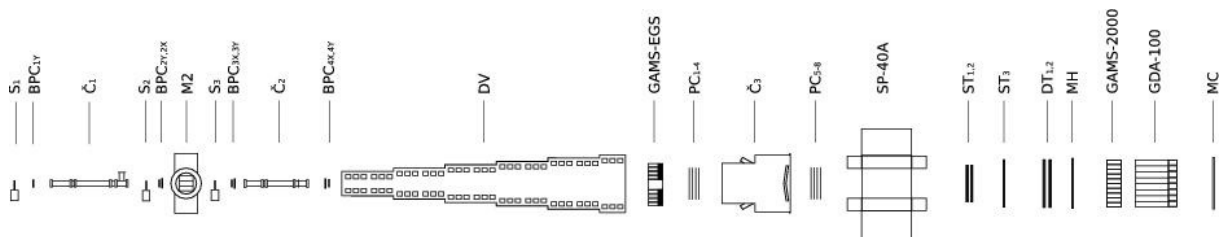


Figure 1. OKA setup

setup is a magnetic spectrometer, presented on Fig. 1. It includes:

1. Beam spectrometer on the basis of 7 1mm pitch PC's ( $BPC_{x,y}$ )  $\sim 1500$  channels in total, 4 2mm-thick scintillation counters and 2 threshold Cherenkov counters.

2. Decay volume(DV) with Veto system, 11m long, filled with He, veto system is composed of 670 Lead-Scintillator sandwiches  $20 \times (5 \text{ mm Sc} + 1.5 \text{ mm Pb})$  with WLS readout. The counters are grouped in 300 ADC channels.
3. Main magnetic spectrometer:  $200 \times 140 \text{ cm}^2$  aperture magnet with  $\int Bdl \sim 1 \text{ Tm}$ ; 5K 2 mm pitch PC's; 1K 9 mm Straw's and 300 channels of 40 mm DT's.
4. Gamma detectors: GAMS-2000 ( $\sim 2300 \text{ } 3.8 \times 3.8 \times 45. \text{ cm}^3$  lead glass blocks), large angle detector (EGS) ( $\sim 1050 \text{ } 5 \times 5 \times 42 \text{ cm}^3$  lead glass blocks).
5. Muon detector: GDA-100 Hadron Calorimeter ( $100 \text{ } 20 \times 20 \text{ cm}^2$  iron-scintillator sandwiches with WLS plates readout);  $4 \text{ } 1 \times 1 \text{ m}^2$  Sc counters behind GDA-100.

## 2. Trigger and statistics

Very simple trigger, which is almost "minimum bias" one, has been used during data-taking:

$Tr = S_1 \cdot S_2 \cdot S_3 \cdot \bar{C}_1 \cdot \check{C}_2 \cdot \bar{S}_{bk} \cdot (\Sigma_{GAMS} > MIP)$ . It is a combination of beam Sc counters,  $\check{C}_{1,2}$  threshold Cerenkov counters ( $\check{C}_1$  sees pions,  $\check{C}_2$  pions and kaons),  $S_{bk}$  - a "beam-killer" counter located in the beam-hole of the GAMS gamma-detector.  $\Sigma_{GAMS} > MIP$  is a requirement for the analog sum of amplitudes in the GAMS-2000 to be higher than a MIP signal.

The "OKA" is taking data since 2010, the total available statistics corresponds to  $\sim 15 \text{ MK}_{e3}$  decays. In the present study we use part of the statistics taken in 2012 and 2013.

## 3. $K_{e3}$ decay study.

The data processing starts with the beam particle reconstruction in  $BPC_1 \div BPC_4$ , then the secondary tracks are looked for in  $PC_1 \div PC_8$ ;  $ST_1 \div ST_3$ ;  $DT_1 \div DT_2$  and events with one good positive track are selected. The decay vertex is searched for, and a cut is introduced on the matching of incoming and decay track. The next step is to look for showers in GAMS-2000 and EGS calorimeters. The electron identification is done using the ratio of the energy of the shower to the momentum of the associated track. The E/p distribution is shown in Fig. 2. The particles with  $0.8 < E/p < 1.2$  are accepted as electrons. The events with one charged track identified as electron and two additional showers in ECAL are selected for further processing. The mass spectrum of  $\gamma\gamma$  shows a clean  $\pi^0$  peak at  $M_{\pi^0} = 134.9 \text{ MeV}$  with a resolution of  $\sim 8.5 \text{ MeV}$ . To fight the main background from  $K_{\pi^2}$  decay, the angle between the momentum of the beam kaon  $\vec{p}_K$  and that of the  $e\pi$ -system i.e.  $\vec{p}_e + \vec{p}_\pi$  is considered, see Fig. 2. The background is clearly seen as a peak at zero angles. The cut is  $\alpha > 1.6 \text{ mrad}$ . Further selection is done by the requirement that the event passes  $2C \text{ } K \rightarrow e\nu\pi^0$  fit. The event selection results in  $\sim 5.25 \text{ M}$  events. The surviving background is estimated from MC to be less than 1%.

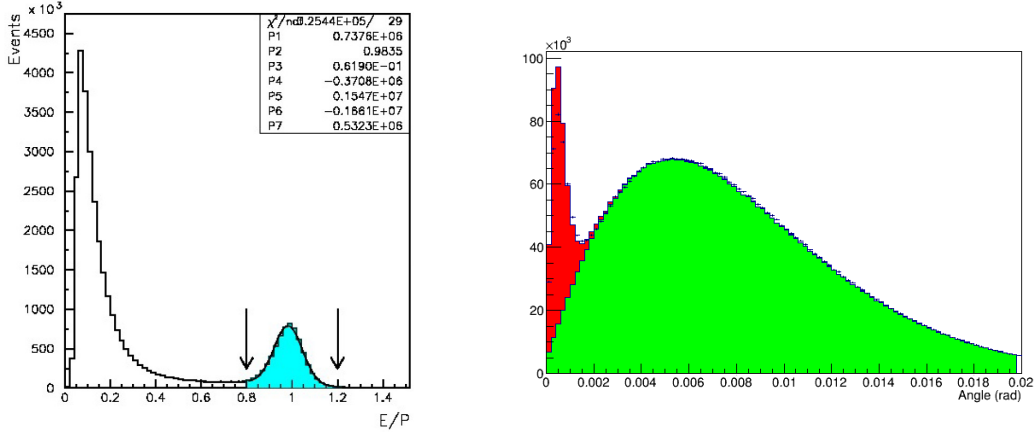


Figure 2. E/P plot - the ratio of the energy of the associated ECAL cluster to the momentum of the charged track (left);  $\alpha$  - the angle between  $\vec{p}_K$  and  $\vec{p}_e + \vec{p}_\pi$  in the lab-system (right).

### 3.1. Analysis

The analysis is based on the fit of the distribution of the events over the Dalitz plot. The variables  $y = 2E_e^*/M_K$  and  $z = 2E_\pi^*/M_K$ , where  $E_e^*$ ,  $E_\pi^*$  are the energies of the electron and  $\pi^0$  in the kaon c.m.s are used. The background events, as MC shows, occupy the peripheral part of the plot. The most general Lorentz invariant form of the matrix element for the decay  $K^+ \rightarrow l^+ \nu \pi^0$  is [4]:  $M = \frac{-G_F V_{us}}{2} \bar{u}(p_\nu)(1 + \gamma^5)[((P_K + P_\pi)_\alpha f_+ + (P_K - P_\pi)_\alpha f_-)\gamma^\alpha - 2m_K f_S - i \frac{2f_T}{m_K} \sigma_{\alpha\beta} P_K^\alpha P_\pi^\beta] v(p_l)$  It consists of vector, scalar and tensor terms.  $f_\pm$  are the functions of  $t = (P_K - P_\pi)^2$ . In the Standard Model (SM) the W-boson exchange leads to the pure vector term. The term in the vector part, proportional to  $f_-$  is reduced(using the Dirac equation) to a scalar form-factor, proportional to  $(m_l/2m_K)f_-$  and is negligible in the case of  $K_{e3}$ . Different parametrizations have been used for  $f_+(t)$ . First is just a Taylor series:  $f_+(t) = f_+(0)(1 + \lambda'_+ t/m_{\pi^+}^2 + \frac{1}{2}\lambda''_+ t^2/m_{\pi^+}^4)$ . It is usually used to compare with ChPT predictions. Alternative parametrization is the pole one:  $f_+(t) = f_+(0)\frac{m_V^2}{m_V^2 - t}$ . The last is a relatively new Dispersive parametrization [5]:  $f_+(t) = f_+(0)\exp(\frac{t}{m_\pi^2}(\Lambda_+ + H(t)))$ . Here  $H(t)$  is a known function. The procedure for the experimental extraction of the parameters  $\lambda_+$ ,  $f_S$ ,  $f_T$ , which was developed in [6] is used. This procedure allows avoiding systematic errors due to the "migration" of the events over the Dalitz plot because of the finite experimental resolution. The radiative corrections were taken into account by reweighting every MC event, according to [7].

### 3.2. Results and comparison with theory

The fit with linear parametrization of the form factor gives  $\lambda_+ = (2.95 \pm 0.022) \times 10^{-2}$ . It could be compared to quite old  $ChPT$   $O(p^4)$  result [8]:  $\lambda_+^{ChPT} = (31.0 \pm 0.6) \times 10^{-3}$ . The results of the fits are summarized in Table 1. The first line is the "standard" fit with

two parameters - linear and quadratic slopes. The quadratic term is quite significant, there is a strong correlation between parameters as it is seen in Fig. 3. The *ChPT*  $O(p^6)$  prediction for the quadratic slope is [9]:  $\lambda_+''(ChPT) = (1.1 \pm 0.1) \times 10^{-3}$ .

$\lambda_+' (10^{-2})$	$m$ [GeV]	$\Lambda_+ (10^{-2})$	$\lambda_+'' (10^{-3})$	$f_t/f_+(0) (10^{-2})$	$f_s/f_+(0) (10^{-3})$
$2.611^{+0.035}_{-0.035}$	$0.891^{+0.003}_{-0.003}$	$2.458^{+0.018}_{-0.018}$	$1.91^{+0.19}_{-0.18}$		
$2.612^{+0.035}_{-0.035}$	$0.891^{+0.004}_{-0.006}$	$2.459^{+0.019}_{-0.018}$	$1.90^{+0.19}_{-0.19}$	$-1.24^{+1.6}_{-1.3}$	$0.13^{+3.8}_{-4.6}$
				$-1.85^{+2.4}_{-1.2}$	$1.95^{+3.7}_{-7.4}$
				$-1.14^{+1.5}_{-1.3}$	$-0.13^{+4.5}_{-3.9}$

Table 1. Results of the data fit with different possible form factors.

The quality of the fit is illustrated by the  $z$  projection of the Dalitz plot, shown on Fig. 3. The second and third lines of the Table 1. correspond to the Pole and Disper-

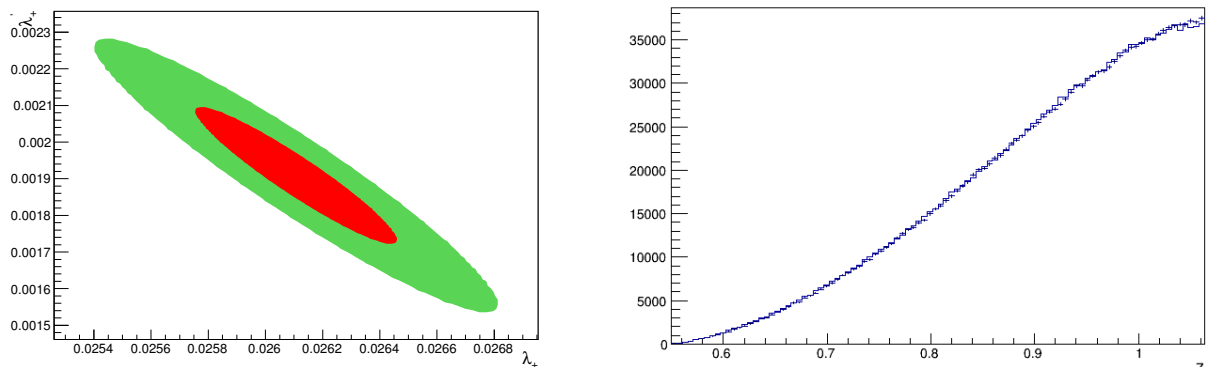


Figure 3.  $\lambda' - \lambda''$  correlation plot (left); Projection of the Dalitz-plot on  $z$  (right) axis. Data is the points with errors; histogram is the fit, corresponding to the 2-nd line of the Table 1.

sion fits respectively. Next lines represent the quadratic, Pole and Dispersion fits with additional tensor and scalar contributions. It is seen, that  $f_S$  and  $f_T$  are not significant.

The main contribution to systematic is coming from the variation of the cut on  $Z$  coordinate of the vertex and the cut on the angle  $\alpha$ . The contributions to the systematic errors from  $Z$  and  $\alpha$  variations are  $(0.021, 0.014) \cdot 10^{-2}$  and  $(0.11, 0.06) \cdot 10^{-3}$  for  $\lambda_+'$  and  $\lambda_+''$  respectively. Finally, we get the results for the quadratic fit:  $\lambda_+' = (2.611 \pm 0.035 \pm 0.028) \cdot 10^{-2}$  and  $\lambda_+'' = (1.91^{+0.19}_{-0.18} \pm 0.14) \cdot 10^{-3}$ .

The result of the Pole fit can be compared to the PDG value for the  $K^*$  mass[10]:  $M_{K^*} = 891.66 \pm 0.26$  MeV. An interpretation of limits on  $F_S$  and  $F_T$  is possible in the framework of the scalar LeptoQuark(LQ) model. Then a diagram with LQ exchange

should be added to the SM diagram with W. Applying Fiertz transformation to the LQ matrix element we get:  $(\bar{s}\mu)(\bar{\nu}u) = -\frac{1}{2}(\bar{s}u)(\bar{\nu}\mu) - \frac{1}{8}(\bar{s}\sigma_{\alpha\beta}u)(\bar{\nu}\sigma^{\alpha\beta}\mu)$ . The first term is the scalar, the second one - tensor. The relation between  $f_S, f_T$  and the Leptoquark scale  $\Lambda_{LQ}$  can be set out ([11]). As a result, a 95% lower limit for the LeptoQuark scale is  $\Lambda_{LQ} > 3.5$  TeV.

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