RECENT QCD-RELATED RESULTS FROM KAON PHYSICS AT CERN (NA48/2 AND NA62)*

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for NA48/2† and NA62‡ collaborations

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The NA48/2 experiment presents a preliminary result of $K_l^\pm$ decays form factors measurement based on the 4.28×10^6 $K_{e3}^\pm$ and 2.91×10^6 $K_{\mu 3}^\pm$ selected decays collected in 2004. The result is competetive with other measurements in $K_{\mu 3}^\pm$ mode and has a smallest uncertainty for $K_{e3}^\pm$, that leads to the most precise combined $K_{l3}^\pm$ result and allows to reduce the form factor uncertainty of $|V_{\mathrm{US}}|$. The NA62 experiment collected a large sample of charged kaon decays with a highly efficient trigger for decays into electrons in 2007. A final result of a new measurement of the electromagnetic transition form factor slope of the neutral pion in the time-like momentum region from the 1.11×10^6 fully reconstructed π^0 Dalitz decays is presented in the second part of this article.

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1. Introduction

The main purpose of the NA48/2 experiment at the CERN SPS was a search for the direct CP violation in $K^\pm$ decay to three pions [1]. The experiment used simultaneous K^+ and K^- beams with momenta of 60 GeV/c propagating through the detector along the same beam line.

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The main components of the NA48/2 detector were a magnetic spectrometer, composed by four drift chambers and a dipole magnet deflecting the charged particles in the horizontal plane, and a liquid krypton electromagnetic calorimeter (LKr) with an energy resolution of about 1% for 20 GeV photons and electrons. For the selection of $K^{\pm}_{\mu 3}$ decays, a muon veto system (MUV) was essential to distinguish muons from pions.

The data used for the form factors (FF) analysis were collected in 2004 during a dedicated run with a special trigger setup which required one or more tracks in the magnetic spectrometer and an energy deposit of at least 10 GeV/c in the electromagnetic calorimeter.

The NA62 experiment collected data during 2007, using the NA48/2 detector, aiming at measuring the ratio R_K of the rates of the leptonic kaon decays. The experiment used modified beam central momentum of 74 GeV/c and different trigger conditions optimized to collect electrons.

2. K_{l3} form factors

Semileptonic kaon decays $K^{\pm} \to \pi^0 l^{\pm} \nu$ (K_{l3}) offer the most precise determination of the CKM matrix element $|V_{\mathrm{US}}|$ [2] that require both a branching ratio and a FF experimental measurement. K_{l3} precision FF measurement results based on the NA48/2 data analysis are presented here.

The K_{l3} decay width in the absence of electromagnetic effects can be represented by the Dalitz plot density depending on the lepton and pion energies in the kaon rest frame E_l and E_π respectively [3]

$$\frac{\mathrm{d}^2\Gamma_0(K_{l3})}{\mathrm{d}E_l \mathrm{d}E_\pi} = N\left(Af_+^2(t) + Bf_+(t)f_-(t) + Cf_-^2(t)\right), \tag{1}$$

where $t = (P_K - P_\pi)^2 = m_K^2 + m_\pi^2 - 2m_K E_\pi$, N is a normalization constant and $f_-(t) = (f_+(t) - f_0(t))(m_K^2 - m_{\pi+}^2)/t$. Here, $f_+(t)$ and $f_0(t)$ are the so-called vector and scalar K_{l3} FF, respectively. m_K is a mass of K^+, m_π is a mass of π^0 and m_{π^+} is a mass of π^+. Definitions of the implemented

TABLE I

Definitions of the FF parameterizations used in the analysis.

	$f_+(t)$	$f_0(t)$
Quadratic	$1 + \lambda'_+ t/m_\pi^2 + \frac{1}{2}\lambda''_+ \left(t/m_\pi^2\right)^2$	$1 + \lambda'_0 t/m_\pi^2$
Pole	$\frac{M_{\mathrm{V}}^2}{\left(M_{\mathrm{V}}^2 - t\right)}$	$\frac{M_{\mathrm{S}}^2}{\left(M_{\mathrm{S}}^2 - t\right)}$
Dispersive	$\exp\left(\frac{(\Lambda_+ + H(t))t}{m_\pi^2}\right)$	$\exp\left(\frac{(\ln[C] - G(t))t}{\left(m_K^2 - m_\pi^2\right)}\right)$

parameterizations are shown in Table I: the quadratic [4] parameterization (fit parameters $\lambda'_+, \lambda''_+, \lambda'_0$), the pole [5] (fit parameters $M_{\rm V}, M_{\rm S}$) and the dispersive [6] one (fit parameters $\Lambda_+, \ln[C]$).

2.1. K_{l3} events reconstruction and selection

The data selection requires one track in the magnetic spectrometer and a time coincidence with at least two clusters in the LKr from a π^0 decay. The track had to be inside the geometrical acceptance of the detector, and needed a proper timing and a momentum $p > 5$ GeV/c in the case of electrons. For muons, the momentum needed to be greater than 10 GeV/c to ensure a proper efficiency of the MUV system. To identify a track as an electron, we require $2.0 > E/p > 0.9$, where E is the energy deposited in the LKr and p is the momentum measured in the spectrometer, and no signal in the MUV system. To identify the track as a muon, we require an associated hit in the MUV system and $E/p < 0.9$.

Longitudinal K_{l3} decay position $Z_{\rm n}$ (neutral vertex Z coordinate) is defined as a longitudinal position of a π^0 decay reconstructed from LKr data assuming the PDG [7] value for π^0 mass. The transverse neutral vertex coordinates $(X_{\rm n}, Y_{\rm n})$ are calculated as the impact point position of the reconstructed charged track on the $Z_{\rm n}$ plane.

For a kaon momentum (P_K) measurement, we direct the Z axis along the beam average position in space, measured from $K^\pm \to \pi^\pm\pi^+\pi^-$ data. In the assumptions of $m(\nu) = 0$ and kaon flight along the beam axis, two solutions of quadratic equation for P_K exist, and the closest to average beam momentum value is chosen.

The background contribution has been estimated by means of the Monte Carlo simulation (MC). For K_{e3}, the background from $K^\pm \to \pi^\pm\pi^0$ (2π) significantly contributes to the selected sample. A cut on the neutrino transverse momentum $P_{\rm t}(\nu) \geq 0.03$ GeV/c is reducing this background below 0.027%.

For $K_{\mu3}$ selection, an essential background may come from 2π decays with a subsequent $\pi^\pm \to \mu^\pm\bar{\nu}$. The cuts on $m(\pi^\pm\pi^0)$ and $m(\mu\bar{\nu})$ reduces the corresponding contamination to 0.0264%. The $K^\pm \to \pi^\pm\pi^0\pi^0$ estimated contribution is about 0.183% for $K_{\mu3}$ and 0.0286% for K_{e3}.

The total statistics of selected data is 4.28×10^6 events for K_{e3}, and 2.91×10^6 events for $K_{\mu3}$ selection.

2.2. Fit procedure and preliminary K_{l3} form factor results

To extract FF, an events-weighting fit is performed for the Dalitz plots defined with 5×5 MeV cells of E_{π^0} *versus* E_l energies in the kaon rest frame. The K_{e3} and $K_{\mu3}$ Dalitz plots were fitted simultaneously with a common

set of the fit parameters. MINUIT [8] package and ROOT [9] interface were used to minimize χ^2 by means of the FF parameters variation, and in such a way the resulting parameter central values, their errors (Table II) and correlation coefficients (Table III) were found. The largest contributions to the systematic uncertaity are related to the beam shape and LKr measurement precision. The fit quality is defined by the following values of χ^2/n.d.f.: 1004.6/1073 for the quadratic parameterization, 1001.1/1074 for the pole and 998.3/1074 for the dispersive one.

TABLE II

Joint fit results for K_{l3} quadratic, pole, dispersive parametrizations ($\times 10^3$).

	λ'_+	λ''_+	λ_0	$M_{\rm V}$	$M_{\rm S}$	Λ_+	$\ln[C]$
Central values	23.35	1.73	14.90	894.3	1185.5	22.67	189.12
Stat. error	0.75	0.29	0.55	3.2	16.6	0.18	4.91
Syst. error	1.23	0.41	0.80	5.4	35.5	0.55	11.09
Total error	1.44	0.50	0.97	6.3	39.2	0.58	12.13

TABLE III

Full uncertainty correlation coefficients for K_{l3} quadratic, pole and dispersive Parametrizations.

	λ''_+	λ_0		$M_{\rm S}$	$\ln[C]$
λ'_+	−0.954	−0.076	$M_{\rm V}$	−0.278	
λ''_+		0.035	Λ_+		−0.035

3. π^0 transition form factor

The decay $\pi^0_{\rm D} \to e^+e^-\gamma$ with a branching fraction of Br = (1.174 ± 0.035)% [7] proceeds through a $\pi^0 \to \gamma\gamma^*$ process with an off-shell photon converting into an e^+e^- pair. The π^0 electromagnetic transition form factor (TFF) describes the deviation of this transition from a point-like interaction.

Kinematic variables x and y, commonly used to describe the Dalitz decay kinematics, are defined in terms of particle four-momenta

$$x = \left(\frac{m_{e^+e^-}}{m^2_{\pi^0}}\right)^2 = \frac{(p_{e^+} + p_{e^-})^2}{m^2_{\pi^0}}, \qquad y = \frac{2p_{\pi^0} \times (p_{e^+} + p_{e^-})^2}{m^2_{\pi^0}(1-x)}. \quad (2)$$

The limits on the variables are given by: $r \le x \le 1$, $-\beta \le y \le \beta$, where $r = \frac{2m_e}{m^0_\pi}$ and $\beta = \sqrt{1 - \frac{r^2}{x}}$. The normalised $\pi^0_{\rm D}$ differential decay width reads

$$\frac{1}{\Gamma\left(\pi^0_{2\gamma}\right)}\frac{\mathrm{d}^2\Gamma\left(\pi^0_{\mathrm{D}}\right)}{\mathrm{d}x\mathrm{d}y} = \frac{\alpha}{4\pi}\frac{(1-x)^3}{x}\left(1+y^2+\frac{r^2}{x}\right)\mid F(x)\mid^2(1+\delta(x,y))\,, \tag{3}$$

where $F(x)$ stands for the π^0 electromagnetic TFF, and $\delta(x,y)$ represents radiative corrections to the π^0_{D} decay. The form factor $F(x)$ is expected to vary slowly in the allowed kinematic region and is parametrised by a linear expression $F(x) = 1 + ax$, where a is the so-called TFF slope parameter.

3.1. Final result of the π^0 TFF slope

The extraction of the π^0 TFF slope from the selected data sample is based on a comparison between the data distribution of the reconstructed x variable, and MC distributions corresponding to different TFF slope values used at the MC generator level. The fit result corresponds to the MC distribution with the best data/MC agreement. Both MC simulation samples ($K_{2\pi\mathrm{D}}$ and $K_{\mu 3\mathrm{D}}$) are included in the MC distribution, since they both contain genuine π^0 Dalitz decays. Selected events were divided into equipopulous bins and a χ^2 test was used for the data/MC histogram comparison. The fit result was then obtained by the χ^2 minimisation.

The most important systematic uncertainties originate from an imprecise simulation of the beam momentum spectrum width, and from the result sensitivity to the spectrometer momentum scale calibration. The NA62 final result for the π^0 TFF slope reads [10]

$$a = (3.68 \pm 0.51_{\mathrm{stat}} \pm 0.25_{\mathrm{syst}}) \times 10^{-2} = (3.68 \pm 0.57) \times 10^{-2}\,, \tag{4}$$

with $\chi^2/\mathrm{n.d.f.} = 54.8/49$, and a p-value of 0.26. The result improves the precision on the π^0 TFF in the time-like momentum region.

4. Conclusion

K_{l3} form factors measurement is performed by NA48/2 experiment on the basis of 4.28×10^6 $K^{\pm}_{e3}$ and 2.91×10^6 $K^{\pm}_{\mu 3}$ events selected from 2004 run data. Result is competetive with the other ones in $K^{\pm}_{\mu 3}$ mode, and a smallest error in $K^{\pm}_{e3}$ has been reached that gives us also the combined result with the smallest error.

The π^0 transition form factor slope parameter is measured using the NA62 experiment data set from 2007. About 1.11 million fully reconstructed π^0 Dalitz decays were selected and studied. The obtained result $a = (3.68 \pm 0.57) \times 10^{-2}$ confirms a positive π^0 TFF slope value with a significance exceeding 6σ. The measured value is compatible with the theoretical predictions.

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