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New results on K physics from NA48 and NA62 experiments

S. Balev
European Organization for Nuclear Research, CERN - CH-1211 Geneve 23, Switzerland

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Summary. — Several analyses from the experiments NA48 and NA62 are presented in this paper, including new measurements with $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ decays, $K^{\pm}_{\mu 3}$ form factors, branching fraction of $K^{\pm} \to \pi^{+}\pi^{-}e^{\pm}\nu$, and precise LFV test with K_{l2} decays.

PACS 13.20.Eb – Decays of K mesons.
PACS 12.15.Hh – Determination of Cabibbo-Kobayashi & Maskawa (CKM) matrix elements.
PACS 11.30.Fs – Global symmetries (*e.g.*, baryon number, lepton number).

1. – Introduction

During 2003 and 2004 the experiment NA48/2 collected a large sample of simultaneously recorded K^+ and K^- decays in order to search for direct CP violation in three-pion final state [1]. Many other precise studies were performed on this multipurpose data-set, taking advantage of the highly symmetric experimental conditions. Sections. **3**, **4** and **5** briefly discuss several of the most recent NA48/2 measurements. In 2007 started the data taking for the first phase of the experiment NA62([1]), dedicated to precise LFV test with K_{l2} decays (sect. **6**).

2. – Experimental setup

The beam line of NA48/2 and the first phase of NA62 experiment is designed to deliver simultaneously K^+ and K^-, produced on a beryllium target from SPS primary protons([2]). The beams of $60\pm3\,\mathrm{GeV}/c$ ($74\pm2\,\mathrm{GeV}/c$) momentum for NA48/2 (NA62) are selected by a system of magnetic elements. After final cleaning and collimation the two beams enter the 114 m long decay volume. The momenta of the charged decay products are measured by a magnetic spectrometer consisting of four drift chambers (DCH) and

([1]) The future program of the experiment, now in advanced stage of construction, is dedicated to 10% measurement of the ultra-rare decay $K^+ \to \pi^+\nu\bar{\nu}$ [2].
([2]) More detailed description and schematic view of the beam line can be found in [1].

a dipole magnet. The resolution of the spectrometer is $\sigma(p)/p = 1.0\% \oplus 0.044\%p$ for NA48/2 and $\sigma(p)/p = 0.5\% \oplus 0.009\%p$ for NA62 (p in GeV/c). A scintillator hodoscope, located after the spectrometer, sends fast trigger signals from charged particles and measures their time with a resolution of 150 ps. The electromagnetic energy of particles is measured by a liquid krypton calorimeter (LKr), a quasi-homogeneous ionisation chamber with an active volume of $10\,\mathrm{m}^3$, $27X_0$ deep and segmented transversely into 13248 cells ($2 \times 2\,\mathrm{cm}^2$ each). The energy resolution is $\sigma(E)/E = 0.032/\sqrt{E} \oplus 0.09/E \oplus 0.0042$ and the spatial resolution in the transverse coordinates x and y for a single electromagnetic shower is $\sigma_x = \sigma_y = 0.42/\sqrt{E} \oplus 0.06\,\mathrm{cm}$ (E in GeV). A muon detector, composed of three planes of plastic scintillator strips, is used for muon identification. A beam pipe traversing the centres of the detectors allows undecayed beam particles and muons from decays of beam pions to continue their path in vacuum. A detailed description of the detector setup can be found in [3].

3. – $K^{\pm}_{\mu 3}$ form factors

3˙1. *Introduction.* – The K_{l3} decays provide the cleanest and most accurate way to access the $|V_{us}|$ element of CKM-matrix. They are described by two form factors $f_{\pm}(t)$, functions of the 4-momentum transfer to the lepton system (t):

$$M = \frac{G_F}{2} V_{us} \left[f_+(t)(P_K - P_\pi)^\mu \bar{u}_l \gamma_\mu (1 - \gamma_5) u_\nu + f_{-(t)} m_l \bar{u}_l (1 + \gamma_5) u_\nu \right]$$

The form factor $f_-(t)$ can be measured with $K_{\mu 3}$ only (and not with K_{e3} due to $m_e \ll M_K$). A linear combination of the two form factors can be defined: $f_0(t) = f_+(t) + t f_-(t)/(m_K^2 - m_\pi^2)$, with $f_+(0) = f_0(0)$ by construction. $f_+(0)$ is not measurable directly and the form factors are normalised to it: $\bar{f}_+(t) = f_+(t)/f_+(0)$ and $\bar{f}_0(t) = f_0(t)/f_+(0)$. Various parametrisations of the form factors are discussed in subsect. **3**˙3.

3˙2. *Event selection and analysis.* – In order to reconstruct the $K_{\mu 3}$ candidates, it is required the presence of a single track with momentum above 10 GeV/c and with a hit in the muon detector associated with it. The ratio of the energy deposit associated with the track in LKr (E) and the measured momentum by the spectrometer (p) should be $E/p < 0.2$, consistent with muon hypothesis(3). The two photons from π^0 decays are identified as clusters of deposited energy in LKr, away from any other activity in the detector and not associated with tracks. The invariant mass of di-photon system ($m_{\gamma\gamma}$) is calculated assuming a position of the decay vertex, defined by the closest approach of the muon candidate to the nominal beam axis. It is required that $|m_{\gamma\gamma} - m_{\pi^0}| < 10\,\mathrm{MeV}/c^2$. The missing mass in $K^{\pm}_{\mu 3}$ hypothesis $m^2_{miss} = (P_K - P_\mu - P_{\pi_0})^2$ should satisfy the condition $|m^2_{miss}| < 10\,\mathrm{MeV}/c^2$. A cut in $(M_{\pi^\pm\pi^0}, P^t_{\pi^\pm})$ space, where $M_{\pi^\pm\pi^0}$ is the invariant mass of the final state particles in $\pi^\pm$ hypothesis for the track and $p^t_{\pi^0}$ is the transverse momentum of π^0, is used to suppress the dominant $K^{\pm}_{\pi^\pm\pi^0}$ background to 0.6%. The background contribution from $K^{\pm}_{\pi^\pm\pi^0\pi^0}$ is 0.14%. The total amount of selected $K^{\pm}_{\mu 3}$ candidates is $3.4 \cdot 10^6$.

The form factors parameters are extracted by a fit to the Dalitz plot, after background subtraction and acceptance correction. The radiative effects are simulated according to [4], changing the Dalitz plot slope by $\sim 1\%$.

(3) The notation E/p is used with the same meaning in all the other sections of the paper.

3·3. *Results*. – Several parametrisations of the form factors has been studied. For the pole parametrisation $\bar{f}_{+,0}(t) = m^2_{V,S}/(m^2_{V,S} - t)$ which describes exchange of K^* resonances with spin-parity $1^-(0^+)$ and mass $m_V(m_S)$, the following values for the free parameters were found: $m_V = 836 \pm 7_{\rm stat} \pm 9_{\rm syst}$ MeV/c^2; $m_s = 1210 \pm 25_{\rm stat} \pm 10_{\rm syst}$ MeV/c^2. The parametrisation based on dispersive approach [5]:

$$\bar{f}_+(t) = \exp\left[\frac{t}{m^2_\pi}(\Lambda_+ + H(t))\right], \qquad \bar{f}_0(t) = \exp\left[\frac{t}{\Delta_{K\pi}}(\ln C + G(t))\right]$$

gives the following results for the free parameters: $\Lambda_+ = (28.5 \pm 0.6_{\rm stat} \pm 0.7_{\rm syst} \pm 0.5_{\rm theor}) \cdot 10^{-3}$ and $\ln C = (188.8 \pm 7.1_{\rm stat} \pm 3.7_{\rm syst} \pm 5.0_{\rm th}) \cdot 10^{-3}$.

The slope parameters in the linear and quadratic expansion of the form factors in terms of t:

$$\bar{f}_{+,0}(t) = 1 + \lambda_{+,0}\frac{t}{m^2_\pi}, \qquad \bar{f}_{+,0}(t) = 1 + \lambda'_{+,0}\frac{t}{m^2_\pi} + \frac{1}{2}\lambda''_{+,0}\left(\frac{t}{m^2_\pi}\right)^2,$$

are found to be: $\lambda'_+ = (30.3 \pm 2.7_{\rm stat} \pm 1.4_{\rm syst}) \cdot 10^{-3}$, $\lambda''_+ = (1.0 \pm 1.0_{\rm stat} \pm 0.7_{\rm syst}) \cdot 10^{-3}$ and $\lambda_0 = (15.6 \pm 1.2_{\rm stat} \pm 0.9_{\rm syst}) \cdot 10^{-3}$ (there is no sensitivity to λ''_0). The above preliminary results are very competitive with the measurements by other experiments and for the first time use $K^+_{\mu 3}$ decays.

4. – New results with $K^\pm \to \pi^\pm\mu^+\mu^-$

The FCNC decay $K^\pm \to \pi^\pm\mu^+\mu^-$ (denoted $K^\pm_{\pi\mu\mu}$) is induced at 1-loop in SM and its rate is dominated by long-distance contributions, involving one-photon exchange. During the 2003–2004 run the experiment NA48/2 collected a sample of 3120 $K^\pm_{\pi\mu\mu}$ decays, ~ 4.5 times larger than the total world sample, which allowed form factor, rate and asymmetry measurements with improved precision.

In the selection of this decay a presense of three tracks is required, forming a vertex in the decay volume, with only one pion candidate with $E/p < 0.8$. The other two tracks should carry opposite charges and be both consistent with the muon hypothesis (associated hits in the muon detector and $E/p < 0.2$). The invariant mass of the final state is required to be consistent with the nominal kaon mass within ± 8 MeV/c^2. The main source of background is $K^\pm \to \pi^\pm\pi^+\pi^-$ (denoted $K^\pm_{3\pi^\pm}$) with $\pi \to \mu$ decay or mis-identification. This background is estimated to be $(3.3 \pm 0.5_{\rm stat} \pm 0.5_{\rm syst})\%$ from the forbidden "wrong sign" evens $\pi^\mp\mu^\pm\mu^\pm$.

The $K^\pm_{\pi\mu\mu}$ decay is sensitive to a single form factor $W(z)$, where $Z = (M_{\mu\mu}/M_K)^2$ [6]. The results within various models are summarised in table I: 1) Linear: $W(z) = G_F M^2_K f_0(1 + z\delta)$; 2) NLO ChPT [7]; 3) combined framework of ChPT and large-N_c QCD [8]; 4) ChPT parametrisation involving meson masses [9].

The branching ratio of $K^\pm \to \pi^\pm\mu^+\mu^-$ is measured to be $(9.62 \pm 0.21_{\rm stat} \pm 0.11_{\rm syst} \pm 0.07_{\rm ext}) \cdot 10^{-8}$, where the external error is related to the precision of the branching fraction of the normalisation mode $K^\pm_{3\pi^\pm}$. Having a measurement for both kaon charges, we put a limit on the charge asymmetry $|\Delta(K^\pm_{\pi\mu\mu})| < 2.9 \times 10^{-2}$ at 90% CL. A new limit on forward-backward asymmetry is set: $|A_{FB}| < 2.3 \times 10^{-2}$ at 90% CL. Finally 52 "wrong sign" events are observed in the signal region with the expected background of (52.6 ± 19.8) estimated from MC simulation, leading to an upper limit of the $BR(K^\pm \to \pi^\mp\mu^\pm\mu^\pm) < 1.1 \cdot 10^{-9}$ at 90% CL. Full details about the selection procedure, the analysis technique and discussion of the above results can be found in [10].

TABLE I. – *The measured model parameters, their correlation coefficients, χ^2/ndf of the fits, and the model-independent BR.*

Model (1)		$\rho(\lvert f_0\rvert,\delta) = -0.993$				$\chi^2/\mathrm{ndf} = 12.0/15$						
$\lvert f_0\rvert =$	0.470	$\pm$	$0.039_{\mathrm{stat.}}$	$\pm$	$0.006_{\mathrm{syst.}}$	$\pm$	$0.002_{\mathrm{ext.}}$	$=$	0.470	$\pm$	0.040
$\delta =$	3.11	$\pm$	$0.56_{\mathrm{stat.}}$	$\pm$	$0.11_{\mathrm{syst.}}$			$=$	3.11	$\pm$	0.57
Model (2)		$\rho(a_+,b_+) = -0.976$				$\chi^2/\mathrm{ndf} = 14.8/15$					
$a_+ =$	-0.575	$\pm$	$0.038_{\mathrm{stat.}}$	$\pm$	$0.006_{\mathrm{syst.}}$	$\pm$	$0.002_{\mathrm{ext.}}$	$=$	-0.575	$\pm$	0.039
$b_+ =$	-0.813	$\pm$	$0.142_{\mathrm{stat.}}$	$\pm$	$0.028_{\mathrm{syst.}}$	$\pm$	$0.005_{\mathrm{ext.}}$	$=$	-0.813	$\pm$	0.145
Model (3)		$\rho(\tilde{\mathrm{w}},\beta) = 0.999$				$\chi^2/\mathrm{ndf} = 13.7/15$					
$\tilde{\mathrm{w}} =$	0.064	$\pm$	$0.014_{\mathrm{stat.}}$	$\pm$	$0.003_{\mathrm{syst.}}$			$=$	0.064	$\pm$	0.014
$\beta =$	3.77	$\pm$	$0.61_{\mathrm{stat.}}$	$\pm$	$0.12_{\mathrm{syst.}}$	$\pm$	$0.02_{\mathrm{ext.}}$	$=$	3.77	$\pm$	0.62
Model (4)		$\rho(M_a,M_\rho) = 0.999$				$\chi^2/\mathrm{ndf} = 15.4/15$					
$M_a/(\mathrm{GeV}/c^2) =$	0.993	$\pm$	$0.083_{\mathrm{stat.}}$	$\pm$	$0.016_{\mathrm{syst.}}$	$\pm$	$0.001_{\mathrm{ext.}}$	$=$	0.993	$\pm$	0.085
$M_\rho/(\mathrm{GeV}/c^2) =$	0.721	$\pm$	$0.027_{\mathrm{stat.}}$	$\pm$	$0.005_{\mathrm{syst.}}$	$\pm$	$0.001_{\mathrm{ext.}}$	$=$	0.721	$\pm$	0.028
$\mathrm{BR}\times 10^8 =$	9.62	$\pm$	$0.21_{\mathrm{stat.}}$	$\pm$	$0.11_{\mathrm{syst.}}$	$\pm$	$0.07_{\mathrm{ext.}}$	$=$	9.62	$\pm$	0.25

5. – Measurement of $K^\pm \to \pi^+\pi^- e^\pm\nu$ branching fraction

5˙1. *Introduction.* – The semileptonic $K^\pm \to \pi^+\pi^- e^\pm\nu$ decay (denoted K_{e4}^{+-}) is one of the richest kaon decays, providing possibility for precise tests of ChPT. The hadronic part of the matrix element can be described in terms of two axial (F and G) and one vector (H) complex form factors [11]. Their expansions into partial s and p waves are further developed in Taylor series in $q^2 = M_{\pi\pi}^2/4m_{\pi^\pm}^2 - 1$ and $M_{e\nu}^2/4m_{\pi^\pm}^2$, where $M_{\pi\pi}$ and $M_{e\nu}$ are the invariant masses of the di-pion and di-lepton systems, respectively. This allows to determine the form factor parameters from the experimental data: $F = F_s e^{i\delta_s} + F_p \cos\theta_\pi e^{i\delta_p}$, $G = G_p e^{i\delta_g}$, $H = H_p e^{i\delta_h}$, where $F_s = f_s + f_s' q^2 + f_s'' q^4 + f_e' M_{e\nu}^2/4m_\pi^2$, $F_p = f_p + f_p' q^2$, $G_p = g_p + g_p' q^2$, $H_p = h_p + h_p' q^2$.

Recently NA48/2 published a precise measurement of the relative form factors of K_{e4}^{+-} decays (normalised to f_s) and $\pi\pi$–scattering lengths [12]. In order to access the absolute form factors with high precision, a new measurement of the decay probability (which is proportional to f_s^2) was performed by NA48/2.

5˙2. K_{e4}^{+-} *selection and background estimation.* – Since the kaon flux is not measured, the branching ratio of K_{e4}^{+-} is calculated by normalising to the most suitable decay: $K_{3\pi^\pm}^\pm$. It is not only topologically similar, but its branching ratio is known with relatively good precision of 0.72% [13]. The selection procedures for the two decay modes share significant common part, which allows to minimise various systematic effects. The presence of three reconstructed tracks in the spectrometer forming a good vertex within the decay volume is required. No hits in the muon detector should be associated with the tracks. For K_{e4}^{+-} one of the tracks is required to be an electron candidate ($E/p > 0.9$). Additional π-e separation is achieved by using a highly efficient linear discriminant variable, which takes into account the shower shape and its relative position with respect to the corresponding track. The two other tracks (opposite charges) are required to have

$E/p < 0.8$ consistent with pion hypothesis. A cut in the $(M_{3\pi}, p^t)$ space is used in order to suppress the background from $K^{\pm}_{3\pi^{\pm}}$, where $M_{3\pi}$ is the invariant mass of the three tracks in pion hypothesis and p^t is the transverse momentum of the system. Additional cuts are applied against $K_{\pi\pi^0\pi^0}$ and $K_{\pi\pi^0}$ with Dalitz decays of π^0. Fixing the kaon mass and the direction of the beam at their nominal values, the four-momentum conservation leads to a quadratic equation for the kaon momentum p_K due to the undetected neutrino. If solution in the range (54-66) GeV/c exists, the event is kept and the closest solution to the nominal beam momentum (60 GeV/c) is assigned to p_K. The three tracks in the $K_{3\pi}$ selection are required to have $E/p < 0.8$ and invariant mass consistent with m_K within $\pm 12\,\mathrm{MeV}/c^2$.

A total of $1.11 \cdot 10^6$ events passes the full K^{+-}_{e4} selection ($7.12 \cdot 10^5$ K^+ and $3.97 \cdot 10^5$ K^-). The number of selected $K^{\pm}_{3\pi^{\pm}}$ decays for normalisation is $1.9 \cdot 10^9$.

The main source of background in K^{+-}_{e4} sample is coming from $K^{\pm}_{3\pi^{\pm}}$ decays with a pion misidentified as an electron, or with $\pi \to e$ decay. Since the $K^{\pm} \to e^{\mp}\pi^{\pm}\pi^{\pm}$ decay is suppressed by a factor of 10^{-10} due to $\Delta S = \Delta Q$ rule, counting these "wrong sign" events gives direct access to the expected $K^{\pm}_{3\pi^{\pm}}$ contamination (divided by 2) in K^{+-}_{e4} sample. With the described selection, the background is at the level of 0.95%. This estimation is confirmed by Monte Carlo simulation with 15% precision. The other components of the background are negligible.

5·3. *Branching ratio calculation, systematic uncertainties and results.* – The branching ratio of K^{+-}_{e4} is calculated as

$$BR(K^{+-}_{e4}) = \frac{N_{K_{e4}} - 2 \cdot N_{WS}}{N_{K_{3\pi}}} \cdot \frac{A_{K_{3\pi}}}{A_{K_{e4}}} \cdot \frac{\epsilon_{K_{3\pi}}}{\epsilon_{K_{e4}}} \cdot BR(K_{3\pi})\,,$$

where $N_{K_{e4}}$ and $N_{K_{3\pi}}$ are the number of selected signal and normalisation candidates, and N_{WS} is the number of "wrong sign" events. The acceptances for both modes $A_{K_{e4}} = 18.22\%$ and $A_{K_{3\pi}} = 24.18\%$ are calculated using the detailed MC simulation of the experimental setup, based on Geant3. The trigger efficiencies for both modes are measured on control samples and found to be $\epsilon_{K_{e4}} = 98.3\%$ and $\epsilon_{K_{3\pi}} = 97.5\%$. Finally $BR(K_{3\pi}) = (5.59 \pm 0.04)\%$ is the branching ratio of $K^{\pm}_{3\pi^{\pm}}$ decay mode [13], determinig the external error of the result.

The following relative systematic uncertainties for $BR(K^{+-}_{e4})$ are considered: 0.18% from acceptance estimation and beam geometry; 0.16% from the performance of the muon vetoing; 0.15% from accidental activity in the detectors; 0.14% from the background estimation; 0.09% from particle identification; 0.08% from the simulation of the radiative effects. The total relative systematic error is 0.35%.

The preliminary result on the total data set is $BR(K^{+-}_{e4}) = (4.279 \pm 0.004_{\mathrm{stat}} \pm 0.005_{\mathrm{trig}} \pm 0.015_{\mathrm{syst}} \pm 0.031_{\mathrm{ext}}) \cdot 10^{-5} = (4.279 \pm 0.035) \cdot 10^{-5}$ (including the radiative K^{+-}_{e4} decays). The trigger error is related to the limited control sample used for efficiency measurement. The total error is three times smaller than the current world average [13]. The branching ratios for both positive and negative kaons are compatible: $BR(K^{+}_{e4}) = (4.277 \pm 0.009) \cdot 10^{-5}$ and $BR(K^{-}_{e4}) = (4.283 \pm 0.012) \cdot 10^{-5}$ (only the combined statistical and trigger error is quoted). This is the first measurement performed for negative kaons. The ratio of the decay probabilities for K^{+-}_{e4} and $K_{3\pi}$ is $(7.654 \pm 0.030) \cdot 10^{-4}$, where the quoted total error is 5 times smaller than the world average. An estimation of the absolute form factors using the new branching fraction measurement is in progress.

6. – Lepton flavour violation test with NA62

6·1. *Introduction.* – The ratio of kaon leptonic decay rates $R_K = \Gamma(K^\pm_{e2})/\Gamma(K^\pm_{\mu 2})$ is known in the SM with excellent precision due to cancellation of the hadronic effects: $R_K^{SM} = (m_e/m_\mu)^2(\frac{m_K^2-m_e^2}{m_K^2-m_\mu^2})^2(1+\delta R_{QED}) = (2.477 \pm 0.001) \times 10^{-5}$ [14], where $\delta_{QED} = (-3.78 \pm 0.04)\%$ is a correction due to the inner bremsstrahlung (IB) $K_{l2\gamma}$ process which is included by definition into R_K(4). Being helicity suppressed due to $V-A$ structure of the charged weak current, R_K is sensitive to non-SM effects. In particular MSSM allows non-vanishing $e-\tau$ mixing, mediated by H^+, which can lead to few percent enhancement of R_K [15].

The present world average of $R_K = (2.493 \pm 0.031) \times 10^{-5}$ is dominated by the recent KLOE final result [16]. The NA62 experiment collected data during 2007 and 2008 aiming to reach accuracy of $\sim 0.4\%$. The final result on partial data set is presented here.

6·2. *Analysis strategy.* – Due to the topological similarity of K_{e2} and $K_{\mu 2}$ decays a large part of the selection conditions are common for both decays. We require the presence of single reconstructed charged track with momentum $13\,\text{GeV}/c < p < 65\,\text{GeV}/c$ (the lower limit is due to the 10 GeV LKr energy deposit requirement in K_{e2} trigger). The track extrapolated to DCH, LKr and HOD should be within their geometrical acceptances. The CDA between the charged track and the nominal kaon beam axis should be less than 1.5 cm. The event is rejected if a cluster in the LKr with energy larger than 2 GeV and not associated with track is present, in order to suppress the background from other kaon decays.

A kinematical separation between K_{e2} and $K_{\mu 2}$ for low track momenta is possible, based on the reconstructed missing mass, assuming the track to be an electron or a muon: $M^2_{\text{miss}}(l) = (P_K - P_l)^2$, where P_l ($l = e, \mu$) is the four-momentum of the lepton. Since the kaon four-momentum P_K is not measured directly in every event, its average is monitored in each SPS spill with fully reconstructed $K^\pm \to 3\pi^\pm$ decays. A cut $M_1^2 < M^2_{\text{miss}}(e) < M_2^2$ is applied to select K_{e2} candidates, and $M_1^2 < M^2_{\text{miss}}(\mu) < M_2^2$ for $K_{\mu 2}$ ones, where M_1^2 and M_2^2 vary from 0.010 to 0.016 $(\text{GeV}/c^2)^2$ for different track momenta, depending on M_{miss} resolution. Particle identification is based on the ratio E/p. Particles with $0.95 < E/p < 1.1$ for $p > 25\,\text{GeV}/c$ and $0.90 < E/p < 1.1$ otherwise(5), are identified as electrons, while particles with $E/p < 0.85$ as muons.

The analysis is based on counting the number of reconstructed K_{e2} and $K_{\mu 2}$ candidates with the selection described above. Since the decays are collected simultaneously, the result does not depend on kaon flux measurement and the systematic effects due to the detector efficiency cancel to first order. To take into account the momentum dependence of signal acceptance and background level, the measurement is performed independently in bins of reconstructed lepton momentum. The ratio R_K in each bin is computed as

$$R_K = \frac{1}{D} \cdot \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \cdot \frac{f_\mu \times A(K_{\mu 2}) \times \epsilon(K_{\mu 2})}{f_e \times A(K_{e2}) \times \epsilon(K_{e2})} \cdot \frac{1}{f_{\text{LKr}}}, \tag{1}$$

(4) Unlike the structure dependent (SD) $K_{l2\gamma}$.

(5) The background to K_{e2} is concentrated in the region $p > 25\,\text{GeV}/c$, hence the need of tighter electron ID.

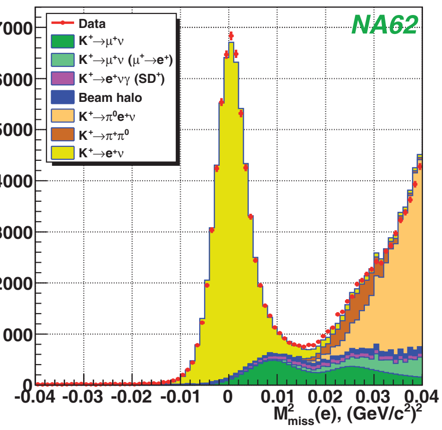

Fig. 1. – $M^2_{\rm miss}(e)$ distributions for K_{e2} candidates and for various backgrounds.

where $N(K_{l2})$ are the numbers of selected K_{l2} candidates ($l = e, \mu$), $N_B(K_{l2})$ are numbers of background events, f_l are efficiencies of electron and muon identification criteria, $A(K_{l2})$ are geometrical acceptances, $\epsilon(K_{l2})$ are trigger efficiencies, $f_{\rm LKr}$ is the global efficiency of the LKr readout, and $D = 150$ is the downscaling factor of the $K_{\mu 2}$ trigger. In order to compute $A(K_{l2})$, a detailed Geant3-based Monte-Carlo simulation is employed.

6·3. *Backgrounds.* – $N_B(K_{e2})$ in (1) is dominated by $K_{\mu 2}$ events with track misidentified as electron, mainly in case of high energetic bremsstrahlung after the magnetic spectrometer, when the photon takes more than 95% of muon's energy. The probability for such process is measured directly by clean sample of muons passing $\sim 10X_0$ of lead (Pb) before hitting the LKr. A Geant4 simulation is used to evaluate the Pb correction to the probability for muon misidentification which occurs via two principal mechanisms: 1) muon energy loss in Pb by ionisation, dominating at low momenta; 2) bremsstrahlung in the last radiation lengths of Pb increasing the probability for high track momenta. The background is evaluated to be $(6.11 \pm 0.22)\%$.

Since the incoming kaon track is not measured and the signature of K_{l2} decays is a single reconstructed track, the background from beam halo should be considered. The performance of the muon sweeping system results in lower background in K^+_{e2} sample ($\sim 1\%$) than in K^-_{e2} sample ($\sim 20\%$), therefore $\sim 90\%$ of data were collected with the K^+ beam only, and small fractions were recorded with simultaneous beams and K^- beam only. The halo background in K^+_{e2} was measured to be $(1.16 \pm 0.06)\%$ from data, collected without K^+ beam.

The other backgrounds considered are: $(0.27 \pm 0.04)\%$ from $K_{\mu 2}$ with subsequent $\mu \to e$ decay([6]); $(1.07 \pm 0.05)\%$ from $K_{e2\gamma}({\rm SD})$([7]); 0.05% for both K_{e3} and $K_{2\pi}$ decays.

The number of K_{e2} candidates is 59813 before background subtraction. The $M^2_{\rm miss}(e)$ distribution of data events and backgrounds are presented in fig. 1.

([6]) This background is suppressed according to Michel distribution, as muons from $K_{\mu 2}$ decays are fully polarised.

([7]) The recent KLOE measurement [16] is used for this estimation.

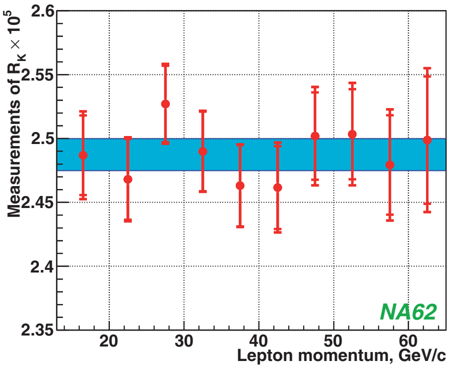

Fig. 2. – R_K measurement in lepton momentum bins. The shaded area indicates the average R_K and its total uncertainty.

6˙4. *Systematic uncertainties and results.* – The electron identification efficiency is measured directly as a function of track momentum and its impact point at LKr using electrons from K_{e3} decays. The average f_e is $(99.27 \pm 0.05)\%$ (f_μ is negligible). The geometric acceptance correction $A(K_{\mu 2})/A(K_{e2})$ is known with permille precision and depends on the radiative $K_{e2\gamma}$(IB) decays, simulated following [17] with higher order corrections according to [18]. The trigger efficiency correction $\epsilon(K_{e2})/\epsilon(K_{\mu 2}) \approx 99.6\%$ is significant only in the first analysis bin $13 < p < 20\,\text{GeV}/c$ and accounts for the difference in the trigger conditions, namely the requirement of $E > 10\,\text{GeV}$ energy deposited in LKr for K_{e2} only. Additional small systematic uncertainty arises due to the global LKr readout efficiency, measured to be $(99.80 \pm 0.01)\%$.

The independent measurements of R_K in track momentum bins are presented in fig. 2. The final NA62 result, based on 40% of the accumulated statistics is $R_K = (2.487 \pm 0.011_{\text{stat}} \pm 0.007_{\text{syst}}) \times 10^{-5} = (2.487 \pm 0.013) \times 10^{-5}$, consistent with SM expectation. The analysis of the whole data set will allow to reach uncertainty of 0.4%.

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