Precision tests of the Standard Model with Kaon decays at CERN

Karim Massri\textsuperscript{1,2}

University of Birmingham, Edgbaston, Birmingham, United Kingdom

E-mail: karim.massri@cern.ch

\textsuperscript{1} On behalf of the NA48/2 Collaboration: G. Anzivino, R. Arcidiacono, W. Baldini, S. Balev, J.R. Batley, M. Behler, S. Bifani, C. Biino, A. Bizzeti, B. Bloch-Devaux, G. Bocquet, N. Cabibbo, M. Calvetti, N. Cartiglia, A. Cecucci, P. Cenci, C. Cerri, C. Cheshkov, J.B. Chêze, M. Clemencic, G. Collazuol, F. Costantini, A. Cotta Ramusino, D. Coward, D. Cundy, A. Dabrowski, P. Dalpiaz, C. Damiani, M. De Beer, J. Derré, H. Dibon, L. DiLella, N. Doble, K. Eppard, V. Falaleev, R. Fantechi, M. Fidecaro, L. Fiorini, M. Fiorini, T. Fonseca Martin, P.L. Frabetti, L. Gatignon, E. Gersabeck, A. Giansanti, S. Giudici, A. Goniède, E. Goudzovski, S. Goy Lopez, M. Holder, P. Hristov, E. Iacopini, E. Imbergamo, M. Jettler, G. Kalmus, V. Kekelidze, K. Kleinknecht, V. Kozhuharov, W. Kubischta, G. Lamanna, C. Lazzeroni, M. Lenti, L. Litov, D. Madigozhin, A. Maier, I. Mannelli, F. Marchetto, G. Marei, M. Markytan, P. Marouelli, M. Martini, L. Masetti, E. Mazzuccato, A. Michetti, I. Mikulec, N. Molokanova, E. Monnier, U. Moosbrugger, C. Morales Morales, D.J. Munday, A. Nappi, G. Neuhofer, A. Norton, M. Patel, M. Pepe, A. Peters, F. Petrucci, M.C. Petrucci, B. Peyaud, M. Piccini, G. Pierazzini, I. Polenkevich, Yu. Potrebenikov, M. Raggi, R. Renk, P. Rubin, G. Ruggiero, M. Savrié, M. Scarra, M. Shieh, M.W. Slater, M. Szőz, S. Stoynev, E. Swallow, M. Szleper, M. Valdata-Nappi, B. Vallage, M. Velasco, M. Velti, S. Venditti, M. Wache, H. Wahl, A. Walker, R. Wanke, L. Wahlmand, A. Winhart, R. Winston, M.D. Wood, S.A. Wotton, A. Zinchenko, M. Ziolkowski.

\textsuperscript{2} On behalf of the NA62 Collaboration: G. Aglieri Rinella, R. Aliberti, F. Ambrosino, A. Antonelli, G. Anzivino, R. Arcidiacono, I. Azhinenko, S. Balev, J. Bendotti, A. Biagioni, C. Biino, A. Bizzeti, T. Blazek, A. Blik, B. Bloch-Devaux, V. Bolotov, V. Bonaito, M. Bragadireanu, D. Britton, G. Britvich, N. Brook, F. Bucci, V. Buescher, F. Butin, E. Capoccia, C. Capuzzo, T. Capussela, V. Carassiti, N. Cartiglia, A. Catinaccio, A. Cecchetti, A. Cecucci, P. Cenci, C. Cerri, O. Chikilev, R. Ciaranfi, G. Collazuol, P. Cooke, P. Cooper, G. Corradi, E. Cortina Gil, F. Costantini, A. Cotta Ramusino, D. Coward, G. D’Agostini, J. Dainton, P. Dalpiaz, H. Danieleson, J. Degrange, N. De Simone, D. Di Filippo, L. Di Lella, N. Dixon, N. Doble, V. Duk, V. Elsha, J. Engel Fried, T. Enik, V. Falaleev, R. Fantechi, L. Federici, M. Fiorini, J. Fry, A. Fucci, L. Fulton, S. Gallorini, L. Gatignon, A. Gianoli, S. Giudici, L. Glonti, A. Goncalves Martins, F. Gonnella, E. Goudzovski, R. Guida, E. Gushchin, F. Hahn, B. Hallgren, H. Heath, F. Herman, D. Hutchcroft, E. Iacopini, O. Jamet, P. Jarron, K. Kaup, V. Karjavin, V. Kekelidze, S. Kholodenko, G. Khoriauli, A. Khudyakov, Yu. Kiryushin, A. Kleinknecht, A. Kluge, M. Koval, V. Kozhuharov, M. Krivda, Y. Kudenko, J. Kunze, G. Lamanna, C. Lazzeroni, R. Leitner, R. Lenci, M. Lenti, E. Leonardi, P. Lichard, R. Lietava, L. Litov, D. Lomidze, A. Lonardo, N. Jurkin, D. Madigozhin, G. Mair, A. Makarov, I. Mannelli, G. Mannocchi, A. Mapelli, F. Marchetto, P. Massarotti, K. Massri, P. Matak, G. Mazza, E. Menichetti, M. Mirra, M. Misheva, N. Molokanova, J. Morant, M. Morel, M. Mouaison, S. Movchan, D. Munday, M. Napolitano, F. Newson, A. Norton, M. Noi, G. Nuesse, V. Obraztsov, S. Padošlki, R. Page, V. Palladino, A. Pardons, E. Pedreschi, M. Pepe, F. Perez Gomez, M. Perrin-Terrin, P. Petrov, F. Petrucci, R. Piandani, M. Piccini, D. Pietreanu, J. Pinzino, M. Pivanti, I. Polenkevich, I. Popov, Yu. Potrebenikov, D. Protopopescu, F. Raffaelli, M. Raggi, P. Riedler, A. Romano, P. Rubin, G. Ruggiero, V. Russo, V. Ryjov, A. Salamon, G. Salina, V. Samsonov, E. Santovetti, G. Saracino, F. Sargeni, S. Schifani, V. Senemov, A. Sergi, M. Serra, S. Shkarovskiy, A. Sotnikov, V. Sougouyaev, M. Sozzi, T. Spadaro, F. Spinella, R. Staley, M. Statera, P. Stulciffe, N. Sziladi, D. Tagan, M. Valdata-Nappi, P. Valente, M. Vasile, V. Vassileva, B. Velghe, M. Velti, S. Venditti, M. Vormstein, H. Wahl, R. Wanke, P. Wertelaers, A. Winhart, R. Winston, B. Wrona, O. Yushchenko, M. Zambrovsky, A. Zinchenko.
Abstract. Recent results and prospects for precision tests of the Standard Model in kaon decay-in-flight experiments at CERN are presented. A measurement of the ratio of leptonic decay rates of the charged kaon at the level of 0.4% precision constrains the parameter space of new physics models with extended Higgs sector, a fourth generation of quarks and leptons or sterile neutrinos. Searches for heavy neutrino mass states and the dark photon in the $\sim 100 \text{ MeV}/c^2$ mass range based on samples collected in 2003-2007 are in progress and prospects will be discussed. The NA62 experiment, starting in 2014, will search for a range of lepton number and lepton flavour violating decays of the charged kaon and the neutral pion at improved sensitivities down to $\sim 10^{-12}$, which will probe new physics scenarios involving heavy Majorana neutrinos or R-parity violating SUSY.

1. Introduction
Since their discovery in late '40s, kaons have been instrumental in understanding the fundamental interactions of nature. The tremendous impact of kaon physics in the development of the Standard Model includes the observation of kaon decay modes with different parity (the so-called "$\varphi - \tau$ paradox"), which led to the discovery of the parity symmetry violation in weak interactions, and the evidence for a second generation of quarks. In fact, the quantum number "strangeness" was introduced to explain the anomalously large lifetime of kaons, which successively led to the postulation of the "strange" quark and the quark model, while the existence of the "charm" quark was hypothesised to explain the observed suppression of the $K_L \to \mu^+\mu^-$ with respect to the charged analogous $K^{\pm} \to \mu^{\pm}\nu$ (GIM mechanism). Another milestone of the kaon physics was to provide the first evidence of indirect and direct CP violation, by the precision measurement of neutral kaon decay rates.

Nowadays, kaon physics is still a unique probe of the flavour sector of the Standard Model (SM). The clean environment allows precise theoretical predictions, which leads to high experimental sensitivity to new physics. An exemplar quantity with such characteristics is the ratio $R_K$ of the leptonic decay rates of the charged kaons, which probes the lepton universality in the SM and is sensitive to a vast number of beyond the SM (BSM) scenarios. In addition, the large statistics of the collected samples allows the study of rare $K^{\pm}$ decay modes, as well as the search for dark matter candidates or forbidden Lepton Number/Flavour Violating (LNFV) decays. The recent results obtained from the NA48/2 and NA62 experiments, the two most recent in a long tradition of fixed-target kaon experiments in the CERN North Area (NA), are presented, and the prospects for the forthcoming three-year long data taking, aimed to precisely measure the branching ratio of the $K^{+} \to \pi^{+}\nu\bar{\nu}$ decay, are discussed.

2. Experimental Apparatus and Data Taking conditions
The NA48/2 experiment at CERN SPS was a multi-purpose $K^{\pm}$ experiment which collected data in 2003-2004, whose main goal was to search for direct CP violation in the $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays [1]. In order to minimise the systematic bias in the comparison between $K^+$ and $K^-$ decays, simultaneous and collinear $K^+$ and $K^-$ beams of the same momentum $(60 \pm 3.7)$ GeV/$c$ were produced by the 400 GeV/$c$ SPS primary proton beam, which impinged on a Beryllium target, and were steered into a 114 m long decay region, contained in a vacuum (at pressure $< 10^{-4}$ mbar) cylindrical tank, to avoid interactions of kaon decay products before detection. Fig. 1 shows the NA48/2 beam line. The downstream part of the vacuum tank was sealed by a convex Kevlar window, that separated the vacuum from the helium at atmospheric pressure in which a magnetic spectrometer, formed of 4 drift chambers (DCHs) and a dipole magnet providing a horizontal momentum kick $p_t = 120 \text{ MeV}/c$, was installed. The magnet polarity was inverted on a daily basis, in order to minimise the systematic bias due to different acceptances for the $K^+$ and $K^-$ decay products. The
spatial resolution of each DCH was $\sigma_x = \sigma_y = 90 \, \mu m$, while the momentum resolution of the spectrometer was $\sigma(p)/p = (1.02 \mp 0.044 \cdot p)\%$, where the momentum $p$ is measured in GeV/c. A hodoscope (HOD), consisting of two planes of 64 scintillator counters each, arranged vertically and horizontally respectively, was placed downstream of the spectrometer and provided fast signals for trigger purposes, as well as time measurements for charged particles with a resolution of $\sim 300$ ps. The HOD was followed by a quasi-homogeneous ionisation chamber, built for the earlier NA48 experiment as electromagnetic calorimeter, which used $\sim 7 \, m^3$ of liquid krypton (LKr) as active material, with a depth of 127 cm, corresponding to 27 radiation lengths. The front plane had an octagonal shape and was segmented in 13248 cells with size $2 \times 2 \, cm^2$. This choice corresponded to a high calorimeter granularity, considering that the LKr Molière radius is 4.7 cm. The LKr calorimeter energy resolution was measured to be $\sigma_E/E = (3.2/\sqrt{E} \mp 9.0/E \mp 0.42)\%$, where $E$ is the energy expressed in GeV. The space resolution $\sigma_{x,y}$ of the LKr was $\sigma_{x,y} = (4.2/\sqrt{E} \mp 0.6) \, mm$, and the time resolution on the single shower was $\sigma_t = 2.5 \, ns/\sqrt{E}$. Downstream the LKr calorimeter, a hadronic calorimeter, which was made of iron plates alternated with scintillator planes, and three muon veto planes were used for particle identification. The detector layout is sketched in Fig. 2. A detailed description of the detector can be found in Ref. [2].

The NA62 experiment ($R_K$ phase, denoted as NA62-$R_K$), whose main goal was to measure the ratio $R_K$ of the rates of the $K^\pm \rightarrow \ell^\pm\nu$ decays ($\ell = e, \mu$), collected a large minimum bias data sample in 2007-2008 [3]. It was essentially based on the NA48/2 detector with minor changes. The beam momentum was changed to $(74 \pm 1.4) \, GeV/c$ and the spectrometer momentum kick was increased to $p_t = 270 \, MeV/c$, which led to an improved momentum resolution $\sigma(p)/p = (0.48 \mp 0.009 \cdot p)\%$. In addition, the trigger system was modified to collect single track leptonic modes.

3. $R_K$ measurement with the NA62-$R_K$ experiment
Leptonic decays of pseudoscalar mesons ($P^\pm \rightarrow \ell^\pm\nu$, denoted $P_{\ell \ell}$ below) have rates proportional to the charged lepton mass squared $m_\ell^2$, due to helicity considerations. Therefore, the electronic mode $P_{e\ell}$ is strongly suppressed with respect to the muonic one $P_{\mu\ell}$. Moreover, the ratio $R_P$ of leptonic decay rates of the same meson $P$ can be computed very precisely, since it does not dependent on non-perturbative terms, usually the dominant source of errors in
the theoretical evaluation of meson decay rates. In particular, the SM prediction for the ratio $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu2})$ is [4]

$$R_{K}^{\text{em}} = \left(\frac{m_e}{m_\mu}\right)^2 \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \left(1 + \delta R_{\text{em}}\right) = (2.477 \pm 0.001) \times 10^{-5},$$

where $\delta R_{\text{em}} = (-3.79 \pm 0.04)\%$ is an electromagnetic correction. Both the helicity suppression and the preciseness of the theoretical prediction make the ratio $R_K$ very sensitive to possible lepton flavour violating terms of many BSM scenarios, probing the SM lepton universality. Within extensions of the SM involving two Higgs doublets, $R_K$ is sensitive to lepton flavour violating effects induced by loop processes with the charged Higgs boson ($H^\pm$) exchange [5, 6]. A recent study [7] has concluded that $R_K$ can be enhanced by $\mathcal{O}(1\%)$ within the Minimal Supersymmetric Standard Model. However, the potential new physics effects are constrained to $\mathcal{O}(1\%)$ by other observables such as $B_s \to \mu^+\mu^-$ and $B_u \to \tau\nu$ decay rates [8]. On the other hand, $R_K$ is sensitive to the neutrino mixing parameters within SM extensions involving a fourth generation of quarks and leptons [9].

### 3.1. Strategy of the measurement

The analysis strategy is based on counting the numbers of reconstructed $K_{e2}$ and $K_{\mu2}$ candidates collected concurrently. The simultaneous collection of both samples has the advantage of being independent of the absolute beam flux measurement and less dependent on potential systematic effects: trigger efficiencies and time dependent biases cancel at first order. The study is performed independently for 40 data samples (10 bins of reconstructed lepton momentum and 4 samples with different data taking conditions) by computing the ratio $R_K$ as

$$R_K = \frac{1}{D} \cdot \frac{N(K_{e2}) - N_{bkg}(K_{e2})}{N(K_{\mu2}) - N_{bkg}(K_{\mu2})} \cdot \frac{A(K_{\mu2})}{A(K_{e2})} \cdot \frac{f_\mu \times \epsilon(K_{\mu2})}{f_e \times \epsilon(K_{e2})} \cdot \frac{1}{f_{\text{tr}}}.$$  

where $N(K_{\ell2})$ are the numbers of selected $K_{\ell2}$ candidates ($\ell = e, \mu$), $N_{bkg}(K_{\ell2})$ are the numbers of background events, $A(K_{\ell2})/A(K_{e2})$ is the geometric acceptance correction, $f_\ell$ are the efficiencies of $e/\mu$ identification, $\epsilon(K_{\ell2})$ are the trigger efficiencies, $f_{\text{tr}}$ is the global efficiency of the LKr calorimeter readout (which provides the information used for electron identification), and $D = 150$ is the downscaling factor of the $K_{\mu2}$ trigger. A Monte Carlo (MC) simulation is used to evaluate the acceptance correction and the geometric part of the acceptances for most background processes entering the computation of $N_{bkg}(K_{\ell2})$. Particle identification, trigger and readout efficiencies and the beam halo background are measured directly from control data samples. Both $f_\ell$ and $\epsilon(K_{\ell2})$ are well above 99%.

### 3.2. $K^\pm \to \ell^\pm \nu$ selection

Most of the selection criteria are common to both $K_{e2}$ and $K_{\mu2}$ decay modes. These criteria identify events with a single-track topology and without clusters in the LKr not associated to the track via direct energy deposition or bremsstrahlung. $K_{e2}$ and $K_{\mu2}$ decays are distinguished by applying kinematic and particle identification criteria. Kinematic identification is based on the reconstructed squared missing mass $M_{\text{miss}}^2(\ell) = (P_K - P_\ell)^2$, where $P_K$ and $P_\ell$ ($\ell = e, \mu$) are the kaon and the lepton 4-momenta, respectively. The mean $P_K$ is monitored on spill basis using fully reconstructed $K^+ \to \pi^+\pi^+\pi^-$ decays; $P_\ell$ is computed from the measured track momentum, assuming the lepton mass $m_\ell$. A selection condition $M_1^2 < M_{\text{miss}}^2(\ell) < M_2^2$ is applied; the $M_{1,2}^2$ values vary across the lepton momentum bins according to resolution. Lepton type identification is based on the ratio $E/p$ of the energy $E$ released in the LKr calorimeter by the lepton track to its momentum $p$ measured by the spectrometer. A cut on $E/p$ between 0.95 (0.9 at $p < 25$ GeV/c) and 1.1 identifies the electrons; tracks with $E/p < 0.8$ are classified as muons.
3.3. Results

The distributions of the reconstructed squared missing mass $M_{\text{miss}}^2(\ell)$ of $K_{\ell 2}$ candidates ($\ell = e, \mu$) compared with the sums of normalised estimated signal and background components are shown in Figs. 3 and 4. The numbers of selected $K_{e2}$ and $K_{\mu 2}$ candidates are $145,958$ and $4,2817 \times 10^7$, respectively. The background contamination in the $K_{e2}$ sample has been estimated by MC simulations and, where possible, by direct measurements to be $(10.95 \pm 0.27)\%$. The largest background contribution is the $K_{\mu 2}$ decay with a mis-identified muon via the catastrophic bremsstrahlung process in the LKr calorimeter. To reduce the uncertainty due to background subtraction, the muon mis-identification probability $P_{\mu e}$ has been measured as a function of momentum by reconstructing $K_{\mu 2}$ decays and selecting those muons traversing a lead bar, which was temporary installed in front of the LKr calorimeter to reduce electron contamination and covered about 10% of the calorimeter acceptance. The measured probability has been also corrected for the ionization energy loss and bremsstrahlung of muons passing through the lead. The contributions to the systematic uncertainty of the result include the uncertainties on the backgrounds, amount of material upstream of the spectrometer magnet (which influences the detection efficiency via bremsstrahlung and scattering), beam simulation, spectrometer alignment, particle identification and trigger efficiency. The result of the measurement, combined over the 40 independent samples taking into account correlations between the systematic errors, is

$$R_K = (2.488 \pm 0.007_{\text{stat}} \pm 0.007_{\text{syst}}) \times 10^{-5} = (2.488 \pm 0.010) \times 10^{-5}.$$  (3)

The stability of $R_K$ measurements in lepton momentum bins and for the separate data samples is shown in Figs. 5 and 6. The result is consistent with the SM expectation, and the achieved precision dominates the world average, while its error is still one order of magnitude higher than the theoretical prediction uncertainty.

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**Figure 3.** Distribution of the reconstructed squared missing mass $M_{\text{miss}}^2(e)$ of $K_{e2}$ candidates compared with the sums of normalised estimated signal and background components.

**Figure 4.** Distribution of the reconstructed squared missing mass $M_{\text{miss}}^2(\mu)$ of $K_{\mu 2}$ candidates compared with the sums of normalised estimated signal and background components.
4. Search for Heavy Neutrinos with the NA62-$R_K$ experiment

Neutrinos are strictly massless within the SM, due to the absence of right-handed neutrino states. However, since the observation of neutrino oscillations [10] has unambiguously demonstrated the massive nature of neutrinos, right-handed neutrino states must be included. A natural extension of the SM involves the inclusion of sterile neutrinos which mix with ordinary neutrinos to explain several open questions. An example of such a theory is the Neutrino Minimal Standard Model (νMSM) [11, 12]. In this model, three massive right-handed neutrinos are introduced to explain simultaneously neutrino oscillations, dark matter and baryon asymmetry of the Universe: the lightest ($N_1$) has mass $\mathcal{O}(1 \text{ keV})$ and is a dark matter candidate; the others ($N_2$, $N_3$), with masses ranging from $100 \text{ MeV}/c^2$ to few GeV/$c^2$, are responsible for the masses of the SM neutrinos (via see-saw mechanism) and introduce extra CP violating phases to account for baryon asymmetry.

Experimentally, searches for heavy sterile neutrinos are performed either by looking for indirect evidence of their production, e.g. by exploring the positive missing mass spectrum of reconstructed meson decays, or directly, by aiming to detect their decay in a possible final state. Decay searches are usually more sensitive than the production ones, but they have the disadvantage of being model-dependent. The possibility of performing a production search for heavy neutrinos in $K^\pm \rightarrow \mu^\pm \nu_H$ decays, using a subset of the NA62-$R_K$ data sample collected for the $R_K$ measurement, is currently under investigation. The limits of such a measurement are related to the missing mass resolution and to the background, mainly from beam pions and muon halo. Such analysis is expected to be competitive with the most stringent limits from production searches in kaon decays [13, 14] for heavy neutrino masses above $300 \text{ MeV}/c^2$. 

![Figure 5](image1.png)

**Figure 5.** Stability of the $R_K$ measurement versus lepton momentum. The result of the combined fit over the 10 data bins is shown by the horizontal band.

![Figure 6](image2.png)

**Figure 6.** Stability of the $R_K$ measurement for independent data samples. The “Pb/noPb” labels indicate samples with and without the lead bar. The result of the combined fit over the 4 data bins is shown by the horizontal band.
5. Search for Dark Photons with the NA48/2 experiment

A new, light vector gauge boson (called dark photon, $A'$), with weak couplings to charged SM fermions, has been recently introduced to explain the observed rise in the cosmic-ray positron fraction with energy and the muon gyromagnetic ratio ($g - 2$) measurement [15]. In a rather general set of models, the interaction of the dark photon with the visible sector is through kinetic mixing with the Standard Model hypercharge $U(1)$ [16]. In these models, the new coupling constant $\varepsilon$ is proportional to the electric charge and the dark photon couples in exactly the same way to quarks and leptons.

5.1. Strategy of the search

The full NA48/2 data sample is used to search for dark photons produced in $\pi^0$ decays and subsequently decayed, using the following chain: $K^\pm \rightarrow \pi^\pm \pi^0$, $\pi^0 \rightarrow \gamma A'$, $A' \rightarrow e^+e^-$, which has three charged particles and a photon in the final state [17]. The expected branching ratio of the $\pi^0$ decay is [18]

$$B(\pi^0 \rightarrow \gamma A') = 2\varepsilon^2 \left(1 - \frac{m_A^2}{m_{\pi^0}^2}\right)^3 B(\pi^0 \rightarrow \gamma\gamma),$$

(4)

with a kinematic suppression of the decay rate for high dark photon masses $m_{A'}$ approaching $m_{\pi^0}$. In the mass range $2m_e \ll m_{A'} < m_{\pi^0}$ accessible in this analysis, the dark photon is below threshold for all decays into SM charged fermions except $A' \rightarrow e^+e^-$, while the allowed loop-induced decays ($A' \rightarrow 3\gamma$, $A' \rightarrow \nu\bar{\nu}$) are highly suppressed. Therefore, assuming that the dark photon decays only into SM particles, $B(A' \rightarrow e^+e^-) \approx 1$. The expected total dark photon decay width is then [19]

$$\Gamma(A' \rightarrow e^+e^-) = \frac{1}{3}\alpha\varepsilon^2 m_A' \sqrt{1 - \frac{4m_e^2}{m_A'^2}} \left(1 + \frac{2m_e^2}{m_A'^2}\right).$$

(5)

From eq. 5 follows that the maximum dark photon mean path in the NA48/2 reference frame for a fully reconstructed event does not exceed 10 cm and can be neglected for $m_{A'} > 10 \text{ MeV}/c^2$ and $\varepsilon^2 > 5 \times 10^{-7}$, conditions which are satisfied for the present analysis. The dark photon signature is thus characterised by a decay in $e^+e^-$ at the production point (prompt decay), and the 3-track vertex topology can be used without significant acceptance loss. Such a signature, however, is the same of the Dalitz decay $\pi^D_0 \rightarrow e^+e^-$, which therefore represents an irreducible background and determines the sensitivity. The largest $\pi^D_0$ sample, and therefore the largest sensitivity, is obtained from the $K^\pm \rightarrow \pi^\pm \pi^D_0$ decays (denoted $K_{2\pi D}$ below). The selected candidates mainly originate from $K_{2\pi D}$ decays, with 0.15% coming from the semileptonic $K^\pm \rightarrow \pi^0 D\mu^+\nu$ decays (denoted $K_{\rho3D}$ below). Correcting the observed number of candidates for acceptance and trigger efficiency, the total number of $K^\pm$ decays in the 98 m long fiducial decay region for the analysed data sample is found to be $N_K = (1.55 \pm 0.05) \times 10^{11}$, where the quoted error is dominated by the external uncertainty on the $\pi^D_0$ decay branching ratio $B(\pi^D_0)$. A dark photon mass scan (i.e. a search for the dark photon assuming different mass hypotheses with a variable mass step) is performed over the distribution of the $e^+e^-$ invariant mass $m_{ee}$. A dark photon produced in the $\pi^D_0$ decay and decaying promptly to $e^+e^-$ would produce a narrow spike in the spectrum. The mass step of the scan and the width of the dark photon signal mass window around the assumed mass are determined by the resolution $\delta m_{ee}$ on the $e^+e^-$ invariant mass $m_{ee}$. The mass window width has been optimised with MC simulations to obtain the highest sensitivity to the dark photon signal, determined by a trade-off between $\pi^D_0$ background fluctuation and signal acceptance. In total, 398 dark photon mass hypotheses are tested in the range $10 \text{ MeV}/c^2 \leq m_{ee} < 125 \text{ MeV}/c^2$, in which the lower limit is determined by the limited
precision of MC simulation of background at low mass, while the upper limit is dictated by
the signal acceptance dropping to zero. Upper limits at 90% CL on $B(\pi^0 \rightarrow \gamma A')$ in each dark photon mass hypothesis under the assumption $B(A' \rightarrow e^+ e^-) \approx 1$ (which holds for $m_{A'} < 2m_\mu$ if $A'$ decays to SM particles only) are computed using the relation

$$B(\pi^0 \rightarrow \gamma A') = \frac{N_{\text{obs}}}{N_K} \left[ B(K_{2\pi}) A(K_{2\pi D}) + B(K_{\mu3}) A(K_{\mu3 D}) \right]^{-1},$$

(6)

where $N_{\text{obs}}$ is the number of $A' \rightarrow e^+ e^-$ decay candidates, while $A(K_{2\pi D})$ and $A(K_{\mu3 D})$ are the acceptances of the $K_{2\pi D}$ and $K_{\mu3 D}$ decays, evaluated with MC simulation for each considered dark photon mass hypothesis. The largest uncertainty ($\approx 3\%$) on the computed $B(\pi^0 \rightarrow \gamma A')$ is the external one due to $B(\pi^0_0)$ entering via $N_K$, and is neglected. Upper limits at 90% CL on the mixing parameter $\varepsilon^2$ in each considered dark photon mass hypothesis are calculated from those on $B(\pi^0 \rightarrow \gamma A')$ using eq. 4.

5.2. Event selection
The $K_{2\pi D}$ event selection requires a three-track vertex reconstructed in the fiducial decay region formed of a pion ($\pi^\pm$) candidate track and two opposite-sign electron ($e^\pm$) candidate tracks. Charged particle identification is based on the ratio $E/p$ of the energy $E$ released in the LKr calorimeter by the track to its momentum $p$ measured by the spectrometer. A cut on $E/p$ between 0.85 and 1.1 identifies the electrons; tracks with $E/p < 0.85$ are classified as pions. Furthermore, a single isolated LKr energy deposition cluster is required and considered as the photon candidate. A set of tight selection criteria is applied to the energies of the final state particles, their timing and spatial separations. The total reconstructed $\pi^\pm \pi^0$ momentum is required to be consistent with the beam momentum spectrum, and its transverse component with respect to the nominal beam axis is required to be consistent with no missing momentum. The reconstructed invariant mass of the $\pi^\pm \pi^0$ system (Fig. 7) is required to be consistent with the $K^{\pm}$ mass. A sample of $4.687 \times 10^5$ fully reconstructed $\pi^0_0$ decay candidates in the $e^+ e^-$ invariant mass range $m_{ee} > 10$ MeV/$c^2$ with a negligible background is selected (Fig. 8).

5.3. Preliminary results
Confidence intervals at 90% CL for the number of $A' \rightarrow e^+ e^-$ decay candidates in each mass hypothesis of the dark photon scan are computed from the numbers of observed data events in the signal region ($N_{\text{obs}}$), the numbers of $\pi^0_0$ background events expected from MC simulation ($N_{\text{exp}}$) and the uncertainty on the number of expected background events, by using the Rolke-Lopez method [20, 21] assuming Poisson-distributed signal and Gaussian-distributed background. The results obtained in the neighbouring mass hypotheses are highly correlated, as the signal mass window is about 6 times wider than the mass step of the dark photon scan. For the preliminary results, it is assumed conservatively that $N_{\text{obs}} = N_{\text{exp}}$ in cases when $N_{\text{obs}} < N_{\text{exp}}$, as the employed implementation of the method (from the ROOT package) has been found to underestimate the upper limits in that case.

The resulting preliminary dark photon exclusion limits, along with constraints from other experiments [22], the band of parameter space where the discrepancy between the measured and calculated muon $g-2$ values falls into the $\pm 2\sigma$ range [15, 23] due to the dark photon contribution, and the region excluded by the electron $g-2$ measurement, are presented in Fig. 9. The obtained upper limits on $\varepsilon^2$ represent an improvement over the existing results in the dark photon mass range 10-60 MeV/$c^2$, and exclude the muon $g-2$ band in the range 10-100 MeV/$c^2$. The most stringent limits ($6 \times 10^{-7}$) are achieved at $m_{A'} \approx 20$ MeV/$c^2$ where the acceptance for the full decay chain is the highest (reaching 2.5%). The limits weaken at higher $m_{A'}$ due to both the kinematic suppression of the $\pi^0 \rightarrow \gamma A'$ decay and the decreasing acceptance.
6. Prospects for the new NA62 experiment

A major beam and detector upgrade is currently being completed, aimed to achieve the required physics specifications to perform the precise (∼10%) measurement of the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ branching ratio [24]. The key features of the new NA62 detector are

- the positive identification, precise time and momentum measurements of kaon candidates;
• a new low-material spectrometer, contained in vacuum;
• the introduction of hermetic photon vetoes up to 50 mrad;
• redundant particle identification for the kaon decay products.

A detailed description of the status of the detector commissioning can be found in Ref. [25]. The NA62 experiment is expected to collect $\sim 1.5 \times 10^{13}$ $K^+$ decays in three years of data taking, starting from 2015. The enhanced performances of the new experimental apparatus and the unprecedented size of the kaon sample to be collected for the $K^+ \rightarrow \pi^+\nu\bar{\nu}$ analysis allow to substantially improve previous measurements, as the $R_K$, and search unexplored regions for many forbidden kaon decays.

6.1. The $R_K$ measurement

The NA62 experiment is expected to collect a $K_{e2}$ sample at least one order of magnitude larger than the NA62-$R_K$ one, therefore reducing the statistical uncertainty by at least a factor three. In addition, the background contamination to the $K_{e2}$ sample, which contributes to $\sim 50\%$ of the total systematic error of the current $R_K$ measurement, will be reduced at negligible level, thanks to the combined effect of photon vetoes (on kaon decays with $\pi^0$s or $\gamma$s), particle identification (on $K_{\mu2}$ decays) and kaon tagging (on the muon halo). These two effects alone already contribute to an improvement in the $R_K$ precision of a factor 2.5, corresponding to an absolute expected precision of 0.16%, to be compared with the current theoretical precision of 0.04% [4].

6.2. Search for Heavy Neutrinos

In NA62 the missing mass resolution will improve by at least a factor of two, thanks to the new spectrometer operated in vacuum, and the background from kaon decays will be better controlled thanks to the full coverage veto system. In addition, kaon identification will reduce significantly the contribution of the muon halo. Therefore, a production search for heavy neutrinos in $K^\pm \rightarrow \mu^\pm \nu_H$ decays with the NA62 detector will improve significantly the current limits [13, 14], at least for neutrino masses above 300 MeV/$c^2$.

6.3. Search for Dark Photons

The search for the prompt $A' \rightarrow e^+e^-$ decay, as the one performed with the NA48/2 experiment, is limited by the irreducible $\pi_j^0$ background. The sensitivity to $\varepsilon^2$ achievable with the employed method scales as the inverse square root of the integrated beam flux, and therefore this technique is unlikely to advance much below $\varepsilon^2 = 10^{-7}$ in the near future, by exploiting the larger $\pi^0$ sample to be collected by the NA62 experiment. On the other hand, a search with the NA62 experiment for a long-lived (i.e. low $m_{A'}$ and low $\varepsilon^2$) dark photon produced in $\pi^0$ decays would be less affected by the $\pi_j^0$ background, due to the different signature involving a displaced vertex, and its sensitivity is worth investigating.

6.4. Search for LNFV $K^+$ and $\pi^0$ decays

The NA62 data sample will consist of $\sim 1.5 \times 10^{13}$ $K^+$ decays, which will be accompanied by $\sim 3 \times 10^{12}$ $\pi^0$ decays from $K^+ \rightarrow \pi^+\pi^0$ (BR $\approx 21\%$). Studies of the prospects for searches for lepton-flavour (LF) or -number (LN) violating and other forbidden decays with NA62 are underway. Preliminary estimates of the single-event sensitivities (defined as the inverse of the number of accepted decays) give results at the level of $10^{-12}$ for $K^+$ decays to states such as $\pi^+\mu^+\epsilon^\mp$ (LFV), $\pi^+\mu^+\epsilon^+$ (LNFV), and $\pi^-e^+e^+$ or $\pi^-\mu^+\mu^+$ (LNV); and at the level of $10^{-11}$ for $\pi^0$ decays to $\mu^\pm\epsilon^\mp$ [26].
7. Conclusions
Our understanding of the fundamental interactions of nature has been deeply enhanced by kaon physics. Nowadays, after more than 60 years since their discovery, kaons still play a unique role in the experimental challenge of probing the SM flavour sector with ever-increasing precision. Both the NA48/2 and NA62 experiments have and still contribute to this effort: their recent results have been presented here, together with the prospects for the forthcoming three-year long data taking. The most precise measurement of $R_K$ to date has been performed from a sample of about $\sim 150 \times 10^3$ candidates collected by the NA62-$R_K$ experiment. The result is $R_K = (2.488 \pm 0.010) \times 10^{-5}$, consistent with the earlier measurements and with the SM expectation. The experimental uncertainty on $R_K$ is still an order of magnitude larger than the uncertainty on the SM prediction. The possibility of performing a production search for heavy neutrinos in $K^\pm \rightarrow \mu^\pm \nu_H$ decays, using a subset of the NA62-$R_K$ data sample collected for the $R_K$ measurement, is being investigated. Such analysis is expected to be competitive for heavy neutrino masses above $300 \text{MeV}/c^2$. Preliminary results on dark photon search in $\pi^0$ decays, with the NA48/2 experiment, are reported: no signal is observed, and the obtained upper limits of the order of $10^{-6}$ (90% CL) on the mixing parameter $\varepsilon^2$ improve over the world data in the mass range 10-60 MeV/$c^2$. Combined with the other available data, this result rules out the dark photon as an explanation for the muon $(g-2)$ measurement, assuming it couples to SM particles only. The forthcoming three-year long data taking period of the NA62 experiment, after a major beam and detector upgrade, will allow to substantially improve previous measurements, as the $R_K$, and search unexplored regions for heavy sterile neutrinos, dark photons and many forbidden kaon and $\pi^0$ decays, as the LNFV modes.

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