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New measurement of the radiative decay $Ke3\gamma$ at the NA62 experiment at CERN

Michal Koval[*a]

[a] *Charles University*
Faculty of Mathematics and Physics, Institute of Particle and Nuclear Physics
V Holesovickach 2, 180 00 Prague 8, Czech Republic

E-mail: michal.koval@cern.ch

The NA62 experiment at CERN reports new results from the study of the radiative kaon decay $K^+ \to \pi^0 e^+ \nu\gamma$ ($Ke3\gamma$), using a data sample recorded in 2017 and 2018. Preliminary results with the most precise measurement of the $Ke3\gamma$ branching ratio, and a T-asymmetry measurement in the $Ke3\gamma$ decay, are presented.

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*Speaker, for the NA62 Collaboration: A. Akmete, R. Aliberti, F. Ambrosino, R. Ammendola, B. Angelucci, A. Antonelli, G. Anzivino, R. Arcidiacono, T. Bache, A. Baeva, D. Baigarashev, L. Bandiera, M. Barbanera, J. Bernhard, A. Biagioni, L. Bician, C. Biino, A. Bizzeti, T. Blazek, B. Bloch-Devaux, P. Boboc, V. Bonaiuto, M. Boretto, M. Bragadireanu, A. Briano Olvera, D. Britton, F. Brizioli, M.B. Brunetti, D. Bryman, F. Bucci, T. Capussela, J. Carmignani, A. Ceccucci, P. Cenci, V. Cerny, C. Cerri, B. Checcucci, A. Conovaloff, P. Cooper, E. Cortina Gil, M. Corvino, F. Costantini, A. Cotta Ramusino, D. Coward, G. D'Agostini, J. Dainton, P. Dalpiaz, H. Danielsson, M. D'Errico, N. De Simone, D. Di Filippo, L. Di Lella, N. Doble, B. Dobrich, F. Duval, V. Duk, D. Emelyanov, J. Engelfried, T. Enik, N. Estrada-Tristan, V. Falaleev, R. Fantechi, V. Fascianelli, L. Federici, S. Fedotov, A. Filippi, R. Fiorenza, M. Fiorini, J. Fry, J. Fu, A. Fucci, L. Fulton, E. Gamberini, L. Gatignon, G. Georgiev, S. Ghinescu, A. Gianoli, M. Giorgi, S. Giudici, F. Gonnella, K. Gorshanov, E. Goudzovski, C. Graham, R. Guida, E. Gushchin, F. Hahn, H. Heath, J. Henshaw, Z. Hives, E.B. Holzer, T. Husek, O. Hutanu, D. Hutchcroft, L. Iacobuzio, E. Iacopini, E. Imbergamo, B. Jenninger, J. Jerhot, R.W. Jones, K. Kampf, V. Kekelidze, D. Kerebay, S. Kholodenko, G. Khoriauli, A. Khotyantsev, A. Kleimenova, A. Korotkova, M. Koval, V. Kozhuharov, Z. Kucerova, Y. Kudenko, J. Kunze, V. Kurochka, V. Kurshetsov, G. Lanfranchi, G. Lamanna, E. Lari, G. Latino, P. Laycock, C. Lazzeroni, M. Lenti, G. Lehmann Miotto, E. Leonardi, P. Lichard, L. Litov, P. Lo Chiatto, R. Lollini, D. Lomidze, A. Lonardo, P. Lubrano, M. Lupi, N. Lurkin, D. Madigozhin, I. Mannelli, A. Mapelli, F. Marchetto, R. Marchevski, S. Martellotti, P. Massarotti, K. Massri, E. Maurice, A. Mazzolari, M. Medvedeva, A. Mefodev, E. Menichetti, E. Migliore, E. Minucci, M. Mirra, M. Misheva, N. Molokanova, M. Moulson, S. Movchan, M. Napolitano, I. Neri, F. Newson, A. Norton, M. Noy, T. Numao, V. Obraztsov, A. Okhotnikov, A. Ostankov, S. Padolski, R. Page, V. Palladino, I. Panichi, A. Parenti, C. Parkinson, E. Pedreschi, M. Pepe, M. Perrin-Terrin, L. Peruzzo, P. Petrov, Y. Petrov, F. Petrucci, R. Piandani, M. Piccini, J. Pinzino, I. Polenkevich, L. Pontisso, Yu. Potrebenikov, D. Protopopescu, M. Raggi, M. Reyes Santos, M. Romagnoni, A. Romano, P. Rubin, G. Ruggiero, V. Ryjov, A. Sadovsky, A. Salamon, C. Santoni, G. Saracino, F. Sargeni, S. Schuchmann, V. Semenov, A. Sergi, A. Shaikhiev, S. Shkarovskiy, M. Soldani, D. Soldi, M. Sozzi, T. Spadaro, F. Spinella, A. Sturgess, V. Sugonyaev, J. Swallow, A. Sytov, G. Tinti, A. Tomczak, S. Trilov, P. Valente, B. Velghe, S. Venditti, P. Vicini, R. Volpe, M. Vormstein, H. Wahl, R. Wanke, V. Wong, B. Wrona, O. Yushchenko, M. Zamkovsky, A. Zinchenko.

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1. Introduction

This proceedings summarizes preliminary results from the $K^+ \to \pi^0 e^+ \nu \gamma$ decay analysis using the NA62 data collected in 2017 and 2018 [1].

The $K^+ \to \pi^0 e^+ \nu \gamma$ decay is described in the *Chiral Perturbation Theory (ChPT)*; calculations of its branching ratio are in [2–5]. The ratio between $K^+ \to \pi^0 e^+ \nu \gamma$ ($Ke3\gamma$) and $K^+ \to \pi^0 e^+ \nu$ ($Ke3$) branching fractions is defined as follows:

$$R_j = \frac{\mathcal{B}(Ke3\gamma^j)}{\mathcal{B}(Ke3)} = \frac{\mathcal{B}(K^+ \to \pi^0 e^+ \nu \gamma \mid E_\gamma^j,\, \theta_{e,\gamma}^j)}{\mathcal{B}(K^+ \to \pi^0 e^+ \nu(\gamma))}, \tag{1}$$

where E_γ^j and $\theta_{e,\gamma}^j$ represent restrictions to the phase space in terms of the radiative photon energy E_γ and the angle $\theta_{e,\gamma}$ between the radiative photon and the charged lepton, due to the divergent decay amplitude for $E_\gamma \to 0$ and $\theta_{e,\gamma} \to 0$. The most commonly used definitions for the R_j kinematic regions in the kaon rest frame are given in Table 1, together with the corresponding recent theoretical and experimental results. The most recent theoretical calculation [5] provides an absolute branching ratio only for the R_2 kinematic region, and corresponds to $R_2 = (0.56 \pm 0.02) \cdot 10^{-2}$.

	E_γ^j	$\theta_{e,\gamma}^j$	$O(p^6)$ *ChPT*	ISTRA+	OKA
$R_1 \times 10^2$	$E_\gamma > 10\ MeV$	$\theta_{e,\gamma} > 10°$	1.804 ± 0.021	$1.81 \pm 0.03 \pm 0.07$	$1.990 \pm 0.017 \pm 0.021$
$R_2 \times 10^2$	$E_\gamma > 30\ MeV$	$\theta_{e,\gamma} > 20°$	0.640 ± 0.008	$0.63 \pm 0.02 \pm 0.03$	$0.587 \pm 0.010 \pm 0.015$
$R_3 \times 10^2$	$E_\gamma > 10\ MeV$	$0.6 < \cos\theta_{e,\gamma} < 0.9$	0.559 ± 0.006	$0.47 \pm 0.02 \pm 0.03$	$0.532 \pm 0.010 \pm 0.012$

Table 1: R_j definitions in terms of E_γ and $\theta_{e,\gamma}$ in the kaon rest frame, and the respective expectations from the $O(p^6)$ *ChPT* calculations [4] and results of the measurements performed by the ISTRA+ [6] and the OKA [7] experiments.

Possible T-violation effects in the $K^+ \to \pi^0 e^+ \nu \gamma$ process can be studied using the T-odd observable ξ and the corresponding asymmetry A_ξ (see Equation 2):

$$\xi = \frac{\overrightarrow{p_\gamma} \cdot (\overrightarrow{p_e} \times \overrightarrow{p_\pi})}{M_K^3}\ ;\ A_\xi = \frac{N_+ - N_-}{N_+ + N_-}, \tag{2}$$

where N_+ (N_-) is the number of events with positive (negative) value of ξ.

Different theoretical calculations of A_ξ (Standard Model and beyond) [3, 5, 8, 9] give values in the range $[-10^{-4}, -10^{-5}]$, while the current experimental sensitivity is two orders of magnitude worse [6], and it refers only to the range R_3: $A_\xi^{ISTRA+}(R_3) = (1.5 \pm 2.1) \cdot 10^{-2}$.

2. The $K^+ \to \pi^0 e^+ \nu \gamma$ decay at NA62

The NA62 experiment at CERN is designed to measure the $K^+ \to \pi^+ \nu \bar{\nu}$ branching ratio [10]; the beam and the detector are described in [11]. Thanks to auxiliary trigger chains [12], the NA62 physics program comprises most of the K^+ decay channels, including the $K^+ \to \pi^0 e^+ \nu \gamma$ process, studied as the signal in the presented analysis, and its normalization decay channel, $K^+ \to \pi^0 e^+ \nu$.

2.1 R_j measurements

The normalized branching ratio R_j is determined in the following way:

$$R_j = \frac{\mathcal{B}(Ke3\gamma^j)}{\mathcal{B}(Ke3)} = \frac{N^{obs}_{Ke3\gamma^j} - N^{bkg}_{Ke3\gamma^j}}{N^{obs}_{Ke3} - N^{bkg}_{Ke3}} \cdot \frac{A_{Ke3}}{A_{Ke3\gamma^j}} \cdot \frac{\epsilon^{trig}_{Ke3}}{\epsilon^{trig}_{Ke3\gamma^j}}, \tag{3}$$

where $N^{obs}_{Ke3\gamma\,(Ke3)}$ and $N^{bkg}_{Ke3\gamma\,(Ke3)}$ are respectively the number of observed signal and expected background events in the signal (normalization) selection, $A_{Ke3\gamma\,(Ke3)}$ is the acceptance measured with MC simulations and $\epsilon^{trig}_{Ke3\gamma\,(Ke3)}$ is the trigger efficiency, measured with data, for the signal (normalization) selection.

For the normalization channel, $66.4 \cdot 10^6$ are selected; for the signal, $129.6 \cdot 10^3$ events are selected for R_1, $53.6 \cdot 10^3$ events for R_2, $39.1 \cdot 10^3$ events for R_3.

The preliminary results of the measurements of R_j, obtained with data collected by NA62 in 2017 and 2018 runs, are reported in Equation 4, while the error budget is shown in Table 2.

$$\begin{aligned} R_1 &= (1.684 \pm 0.005 \pm 0.010) \cdot 10^{-2}, \\ R_2 &= (0.599 \pm 0.003 \pm 0.005) \cdot 10^{-2}, \\ R_3 &= (0.523 \pm 0.003 \pm 0.003) \cdot 10^{-2}. \end{aligned} \tag{4}$$

Uncertainty source	$\delta R_1/R_1$	$\delta R_2/R_2$	$\delta R_3/R_3$
Statistical	0.3%	0.5%	0.6%
Acceptances from MC	0.2%	0.4%	0.4%
Background estimation	0.1%	0.2%	0.1%
LKr response modeling	0.5%	0.6%	0.5%
Theoretical model	0.1%	0.5%	0.1%
Total systematic	0.6%	0.9%	0.6%
Total (statistical + systematic)	0.7%	1.0%	0.8%

Table 2: Relative uncertainties of the NA62 preliminary measurements of R_j.

2.2 A_ξ measurements

The T-asymmetry is measured using the $K^+ \to \pi^0 e^+ \nu\gamma$ samples selected for each R_j. A raw measurement of A_ξ is obtained applying the formula of Equation 2 directly on the selected data sample: A_ξ^{Data}. It is then corrected by the offset introduced by the reconstruction and the selection, that is measured with the $K^+ \to \pi^0 e^+ \nu\gamma$ MC sample, comparing the generated and the reconstructed values of the asymmetry: $A_\xi^{Offset} = A_\xi^{MCreco} - A_\xi^{MCgene}$. The final measurement is therefore obtained as: $A_\xi = A_\xi^{Data} - A_\xi^{Offset}$. The preliminary results are reported in Table 3.

	R_1 selection	R_2 selection	R_3 selection
A_ξ^{Data} $(\times 10^2)$	0.2 ± 0.3	0.1 ± 0.4	-0.6 ± 0.5
$A_\xi^{MCgene}(\times 10^2)$	-0.01 ± 0.01	0.00 ± 0.02	-0.01 ± 0.02
$A_\xi^{MCreco}(\times 10^2)$	0.3 ± 0.2	0.4 ± 0.3	0.3 ± 0.5
A_ξ $(\times 10^2)$	$-0.1 \pm 0.3_{stat} \pm 0.2_{MC}$	$-0.3 \pm 0.4_{stat} \pm 0.3_{MC}$	$-0.9 \pm 0.5_{stat} \pm 0.4_{MC}$

Table 3: Preliminary results of the NA62 measurements of A_ξ, for the three different kinematic regions of the $K^+ \to \pi^0 e^+ \nu\gamma$ process.

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