# First observation of $\mathrm{K}^\pm \to \pi^\pm \pi^0 e^+ e^-$ decay at NA48

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We report here the first observation by the NA48/2 experiment of the rare decay $\mathrm{K}^\pm \to \pi^\pm \pi^0 e^+ e^-$. From a sample of about 2000 decay candidates collected in 2003, a preliminary value of the branching ratio in the full kinematic space has been obtained as $(4.06 \pm 0.17) \cdot 10^{-6}$.

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## 1. Introduction

The NA48/2 experiment at the CERN SPS has collected in the years 2003-2004 a large sample of charged kaon decays, used primarily in the search for direct CP violation in $K^{\pm} \to 3\pi$ decays, which allowed a large number of rare decay modes studies. We report here the first observation and the preliminary branching ratio measurement of the decay $K^{\pm} \to \pi^{\pm}\pi^0 e^+ e^-$.

The $K^{\pm} \to \pi^{\pm}\pi^0 e^+ e^-$ decay proceeds through virtual photon exchange with an internal conversion into electron-positron pair. The virtual photon is produced either by Internal Bremsstrahlung (IB), emitted by one of the charged mesons in the initial or final state, or by direct emission (DE), radiated at the weak vertex of the intermediate state. The differential decay width consists of three terms: the IB contribution (pure electric part E), the DE component (electric E and magnetic M part) and the interference between all these components [1]. The decay offers then interesting short and long distance parity violating observables. Few theoretical papers are available [1][2][3][4], however the authors of [1] have predicted the branching ratio of the single components of the decay, on the basis of NA48/2 measurements of the magnetic and electric terms in $K^{\pm} \to \pi^{\pm}\pi^0\gamma$ [5]. This decay has never been observed so far.

## 2. The NA48/2 beam

The beam line used in the NA48/2 [6] data taking was specifically designed to simultaneously transport positive and negative particles. The two simultaneous $K^+$ and $K^-$ beams were produced by 400 GeV primary protons from the CERN SPS impinging on a 40 cm long beryllium target. Opposite charge particles, with a central momentum of 60 GeV/$c$ and a momentum band of $\pm 3.8\%$ (rms), were selected by two systems of dipole magnets (each forming an "achromat"), focusing quadrupoles, muon sweepers and collimators. At the entrance of the decay volume, a 114 m long evacuated vacuum tank, the beams contained $\sim 2.3 \cdot 10^6 \, K^+$ and $\sim 1.3 \cdot 10^6 \, K^-$ per pulse of about 4.5 s duration with a flux ratio $K^+/K^-$ close to 1.8. The two beams were focused $\sim$200 m downstream of the production target in front of the first spectrometer chamber.

## 3. The NA48/2 detector

The momenta of charged decay products were measured by a magnetic spectrometer, housed in a tank filled with helium at nearly atmospheric pressure and placed after the decay volume. The spectrometer accomodated four drift chambers composed each of 8 planes of sense wires, and a dipole magnet located between the second and the third DCHs, which gave a horizontal transverse momentum kick to charged particles of 120 MeV/$c$. The corresponding measured spectrometer momentum resolution was $\sigma_p/p = 1.02\% \oplus 0.044\% \, p$ , where the momentum $p$ is expressed in GeV/$c$. A counter hodoscope consisting of two planes of orthogonal plastic scintillator strips producing fast trigger signals was placed after the spectrometer. A 127 cm ($27X_0$) thick liquid krypton electromagnetic calorimeter located further downstream is used to measure energy and position of photons and electrons. Its 13248 readout cells had a transverse size of 2x2 cm$^2$ each without longitudinal segmentation. The energy resolution was $\sigma_E/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$ (E in GeV). The spatial resolution for the transverse coordinates x and y of an isolated electromagnetic

shower was $\sigma_x = \sigma_y = 0.42/\sqrt{E} \oplus 0.06$ cm (E in GeV). A dedicated two-level trigger has been used to collect three-track events with high efficiency. A detailed description of the detector can be found in [7].

## 4. Data selection and background estimates

Event candidates are requested to have three charged tracks and a neutral pion, reconstructed from two photons, pointing to a common vertex in the fiducial region. A charged track is classified as electron/positron if the ratio of the energy in the LKr calorimeter to the momentum from the spectrometer ($E/p$) is larger than 0.85, otherwise the track is assigned to a pion. Two isolated clusters in the calorimeter, not associated to tracks, are identified as photons from the $\pi^0$ decay if their invariant mass is within $\pm 10 \text{MeV}/c^2$ from the nominal PDG $\pi^0$ mass. The invariant mass of the $\pi^\pm \pi^0 e^+ e^-$ is required to be within $\pm 10 \text{MeV}/c^2$ from the nominal PDG $K^\pm$ mass.

The main sources of background to the signal are:

- $K^\pm \to \pi^\pm \pi^0 \pi_D^0 (K_{3\pi D})$ with one lost photon

- $K^\pm \to \pi^\pm \pi_D^0 (\gamma)$

where $\pi_D^0$ denotes the $\pi^0$ Dalitz decay $\pi^0 \to e^+ e^- \gamma$.

The rejection of the $K_{3\pi D}$ background is obtained by requiring the squared invariant mass of the $\pi^\pm \pi^0$ system to be more than $0.12 \text{ GeV}^2/c^4$, as the phase space allowed in the signal mode is larger than in the background one that is limited by the second $\pi^0$ in the final state.

For the $K_{2\pi_D}$ background, both invariant masses $M_{ee\gamma_{1,2}}$ should be more than 7 MeV/$c^2$ away from the $\pi^0$ mass.

A sample of 1916 signal candidates has been selected in the data collected in 2003 with a background contamination below 3%, as predicted by a MonteCarlo simulation ($(26 \pm 5.1)$ from $K_{2\pi D}$ and $(30 \pm 5.5)$ from $K_{3\pi D}$) and shown in Figure 1.

The normalization is the $K_{2\pi D}$ mode, collected concurrently with the signal channel, using the same trigger logic and then selected with a common event reconstruction, in order to cancel systematic effects such as trigger inefficiencies and particle identification (Figure 2). The only background to the normalization channel is the $K_{3\mu D}$ mode ($K^\pm \to \mu^+ \nu \pi_D^0$). The statistics collected in 2003 for the normalization mode is 6.715 million candidates with a background contamination of less than 0.1%.

## 5. Branching ratio measurement

The total branching ratio for $K^\pm \to \pi^\pm \pi^0 e^+ e^-$ is expressed by

$$\mathscr{B}(K^\pm \to \pi^\pm \pi^0 e^+ e^-) = \frac{N_S - N_B}{N_N} \frac{A_N \varepsilon_N}{A_S \varepsilon_S} B(N)$$

where $A_{S,N}, \varepsilon_{S,N}$ are the acceptances and the trigger efficiencies for the signal and normalization channels. $N_S$ is the number of signal events ($N_S = 1916$), $N_B$ is the number of background events ($N_B = 55.8 \pm 7.4$) and $N_N$ is the number of $K_{2\pi D}$ normalization events. The PDG [8] world average
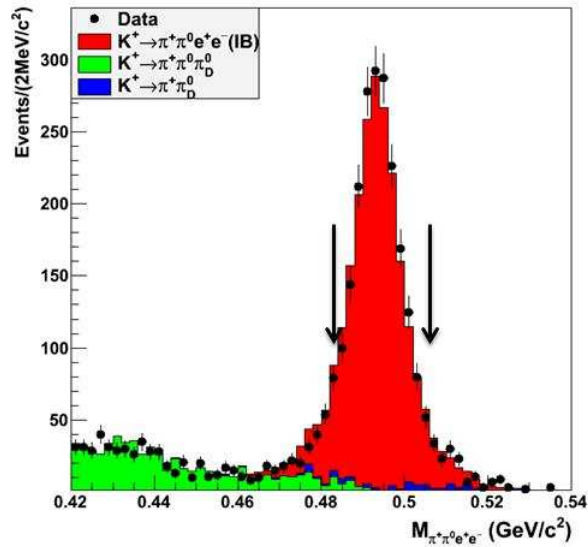
**Figure 1:** Distribution of the $\pi^{\pm}\pi^0 e^+ e^-$ invariant mass for the data and expected background before the final invariant mass cut shown by vertical arrows.
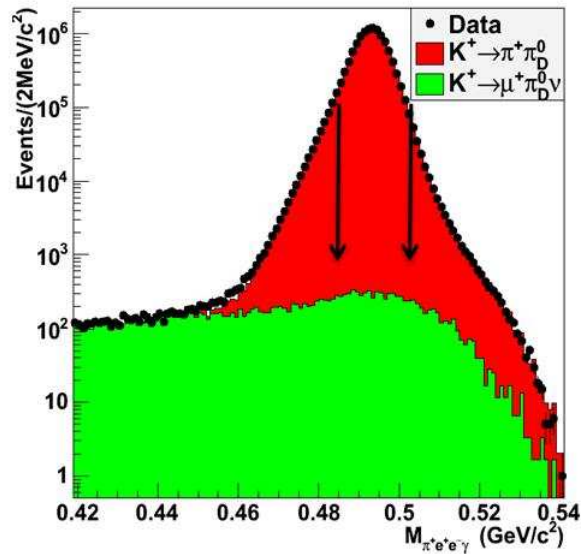


**Figure 2:** Reconstructed invariant mass of the $K_{2\pi D}$ normalization channel and its background before the final cut shown by the vertical arrows.

$B_N = (2.425 \pm 0.076) \cdot 10^{-3}$ is used for the normalization mode branching ratio. All the acceptances have been computed using a GEANT3-based simulation [9] which includes full detector description, the beam line geometry, stray fields and local imperfections. The trigger efficiencies of the two channels are computed from the data and found to be very similar (98%).

The IB, DE (dominated by M) and IB-E interference contributions are simulated separately according to the theoretical description in [1], neglecting the electric contribution and the other

4

interference terms. The signal acceptance has been obtained from a weighted average of the single components acceptances, using the relative fractions computed in [1] as weights. These fractions have been obtained on the basis of the NA48 measurements of the electric and magnetic terms in $K^{\pm} \to \pi^{\pm}\pi^0\gamma$

$$A_S = \frac{A_{IB} + A_{DE} \cdot Frac_{DE} + A_{INT} \cdot Frac_{INT}}{1 + Frac_{DE} + Frac_{INT}}$$

In the quoted paper [1], radiative corrections are not computed, so the NA48/2 simulation included Coulomb corrections and real photon(s) emission, with the PHOTOS package [10].

The preliminary result for the branching ratio is

$$\mathscr{B}(K^{\pm} \to \pi^{\pm}\pi^0 e^+ e^-) = (4.06 \pm 0.10_{stat.} \pm 0.06_{syst.} \pm 0.13_{ext.}) \cdot 10^{-6}$$

The dominant contribution to the overall precision comes from the external error on the normalization mode. The systematic error include contributions from radiative corrections, particle identification, trigger efficiencies and acceptance: this last contribution was obtained by varying the weights in the acceptance calculation, in order to take into account the E and M measurement uncertainties [5].

The comparison with the theoretical predictions is shown in Figure 3. The prediction of [1] ($\mathscr{B} = 4.29 \cdot 10^{-6}$) with no isospin breaking is shown with the short dashed line, while the long dashed line shows the branching ratio corrected for isospin breaking ($\mathscr{B} = 4.19 \cdot 10^{-6}$) as from a private communications from the authors in [1]). The measured value is in agreement within one standard deviation with the theoretical prediction. However the NA48/2 sample statistics is not large enough to be sensitive to DE and INT contributions to the $M_{ee}$ spectrum (Figure 4). In addition it will be difficult to perform a full Dalitz plot analysis without a proper description of the radiative effects.
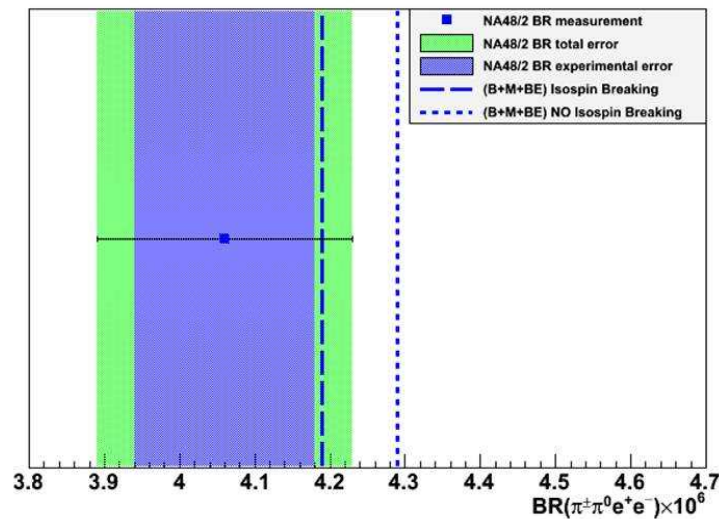


**Figure 3:** Preliminary branching ratio for $K^{\pm} \to \pi^{\pm}\pi^0 e^+ e^-$, with its experimental (shaded blue band) and total (shaded green band) errors
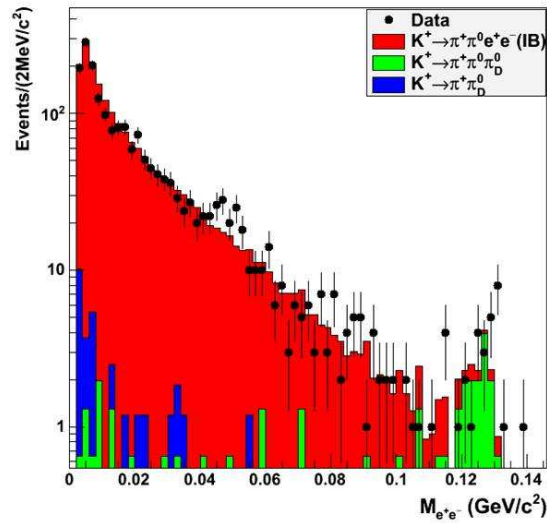
**Figure 4:** Reconstructed $m_{ee}$ invariant mass distribution of the data and simulated background samples. The IB component is sufficient to describe the data distribution within the limited statistics.

## 6. Conclusions

Using data collected in 2003, NA48/2 has performed an analysis of the decay $K^{\pm} \to \pi^{\pm}\pi^0 e^+ e^-$. About 2000 signal events have been observed with a 3% background contamination, leading to the first observation of this decay. The preliminary result for the branching ratio is $\mathscr{B}(K^{\pm} \to \pi^{\pm}\pi^0 e^+ e^-) = (4.06 \pm 0.10_{stat.} \pm 0.06_{syst.} \pm 0.13_{ext.}) \cdot 10^{-6}$. Due to limited statistics, the sample has no sensitivity to the DE and INT contributions to the $M_{ee}$ spectrum.

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