

Measurement of radiative processes at NA48

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Abstract. The first part of this paper will review the new results in the radiative decays of charged kaons available from the NA48/2 experiment at CERN: the first measurement of the DE and INT contribution to the decay $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ in the T_π^* region $0 < T_\pi^* < 80$ MeV and the first observation of $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$ decay. Then in the second part of the paper new results on radiative hyperons decays, concerning the measurement of $\Xi^0 \rightarrow \Lambda \gamma$ decay asymmetry and the first observation of the $\Xi^0 \rightarrow \Lambda e^+ e^-$ decay from NA48/I, will be reported.

1. Introduction

The NA48/I and NA48/II experiments were taking data at CERN in the year 2002 and in the years 2003-2004, respectively. A primary proton beam extracted from the SPS was exploited to produce high intensity secondary beams (neutral or charged). A detailed description of the beam and of the detector is available elsewhere[1].

2. The decay $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$

Presently χ PT is one of the most reliable tools to describe low energy QCD dynamics. Genuine manifestation of the chiral anomaly in non-leptonic decays is found to be restricted to the radiative decay of $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ in the charged kaon sector.

The following three components contribute to the decay amplitude: Inner Bremsstrahlung (IB), Direct Emission (DE) from the vertex and interference (INT) between these two. The amplitude of a $K \rightarrow \pi \pi \gamma$ decay receives contributions from electric and magnetic transitions: electric contributions are dominated by IB while the DE component, arising only at the order $O(p^4)$, consists of both magnetic and electric transitions. While the magnetic part of DE can be determined using the Wess-Zumino-Witten functional, there is no definite prediction in χ PT on the electric transition, whose amplitude depends on undetermined constants. The electric contribution is extremely interesting since it interferes with the IB amplitude and can be distinguished from the magnetic, which does not. The decay rate of $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ can be parametrized using a Lorentz invariant variable:

$$W^2 = \frac{(P_K^* \cdot P_\gamma^*)(P_\pi^* \cdot P_\gamma^*)}{(m_K m_\pi)^2} \quad (1)$$

where P_x^* is the 4-momentum of particle x and γ is the radiative photon. The decay rate then depends only on T_π^* (the kinetic energy of π^\pm in the kaon rest frame) and W , integrating over T_π^* an expression that separates the different contributions into terms with different powers of

Exp.	year	#events	$BR(DE) \cdot 10^{-6}$
E787 [2]	2000	20K	$4.7 \pm 0.8 \pm 0.3$
E470 [3]	2003	4.5K	$3.2 \pm 1.3 \pm 1.0$
E787 [4]	2005	20K	$3.5 \pm 0.6 \pm 0.35$
E470 [5]	2005	10K	$3.8 \pm 0.8 \pm 0.7$

Table 1. DE experimental results for the decay $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$

Effect	syst. DE	syst. INT
Energy scale	0.09	-0.21
LKr non linear	< 0.05	< 0.05
γ misid	-	± 0.2
Fit procedure	0.02	0.019
Resolution diff	< 0.05	< 0.1
LVL1 trigger	± 0.17	± 0.43
LVL2 Trigger	± 0.17	± 0.52
Background	< 0.05	< 0.05
TOTAL	± 0.25	± 0.73

Table 2. Systematic uncertainties for the measurement of the contributions to the decay $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$

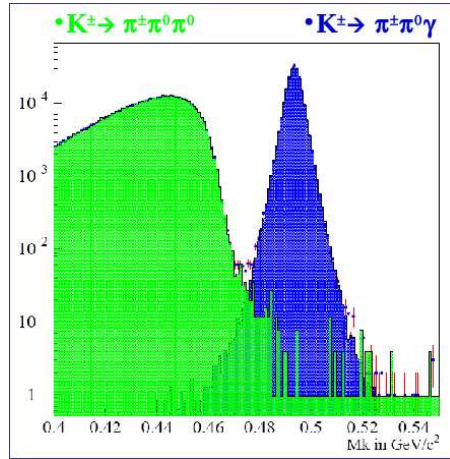


Figure 1. Data - MonteCarlo comparison of M_K spectrum for the decay $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$

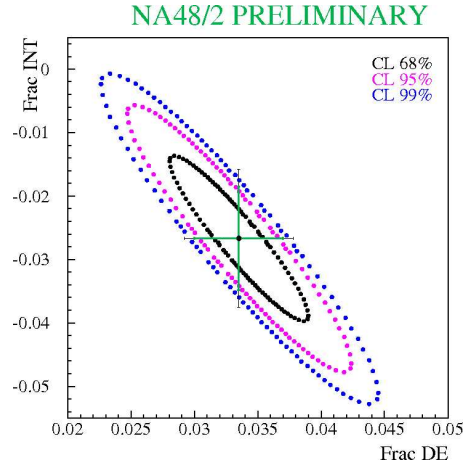


Figure 2. Contour plot for DE and INT components of the decay $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$

W is obtained:

$$\frac{d\Gamma^\pm}{dW} \simeq \left(\frac{d\Gamma^\pm}{dW} \right)_{IB} \left[1 + 2 \left(\frac{m_\pi}{m_K} \right)^2 W^2 |E| \cos((\delta_1 - \delta_0) \pm \phi) + \left(\frac{m_\pi}{m_K} \right)^4 W^4 (|E|^2 + |M|^2) \right]. \quad (2)$$

The three terms represent the IB, INT and DE contributions respectively. Although the DE component is hardly observed, due to the dominant IB, it is isolated kinematically using W .

The IB component of the $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ decay was measured[6] to be in good agreement with QED theoretical predictions. The experimental measurement of the DE and INT fractions is affected by very dangerous background sources due to $K^\pm \rightarrow \pi^\pm \pi^0$ and $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ decays, suppressed in the kinematically background free region, $55 \text{ MeV} < T_\pi^* < 90 \text{ MeV}$. The present experimental knowledge about DE is summarized in Table 1. The results shown have been obtained in the T_π^* region 55-90 MeV assuming vanishing interference. NA48/II has collected the largest world sample of $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$, resulting into about 220000 events passing data selection cuts. Such data sample is very clean, as shown in figure 1, although it has been

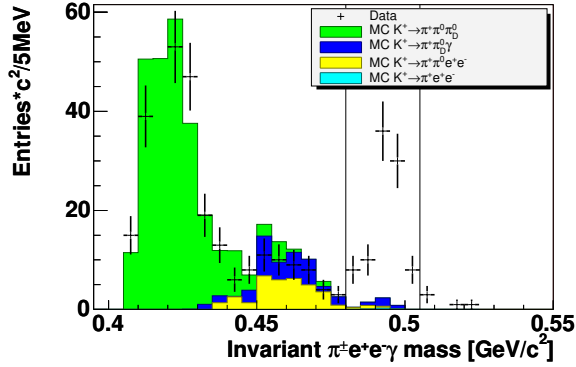


Figure 3. Selected signal candidates and background expectation from MonteCarlo simulation for the decay $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$

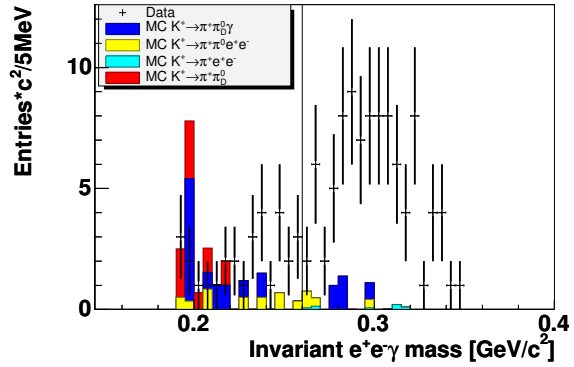


Figure 4. $e^+e^- \gamma$ invariant mass for the decay $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$

decided to accept events also in the low region of T_π^* . Indeed, this region is kinematically accessible to $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ decays when one of the two photons from the π^0 s is lost but it is also the region more sensitive to DE and INT decay amplitudes. An extended maximum likelihood technique, comparing the W spectrum in the data to MonteCarlo W distributions for the 3 components, is used to get the IB, DE and INT fractions. The fit is performed in the W region 0.2-0.9 corresponding to 124000 events from the total sample. After correcting for different acceptances, the results for the fractions of DE and INT with respect to the IB branching ratio in the region $0 < T_\pi^* < 80$ MeV are:

$$\text{Frac(DE)} = (3.35 \pm 0.35_{sta} \pm 0.25_{sys})\% \quad (3)$$

$$\text{Frac(INT)} = (-2.67 \pm 0.81_{sta} \pm 0.73_{sys})\% \quad (4)$$

All results are preliminary. The present measurement is the first evidence for a non vanishing interference term in the $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ channel. The contour plot in Figure 2 shows the very high correlation between the two components.

Many systematic checks, summarized in Table 2, have been performed to study the stability of the result. Systematic uncertainties are dominated by trigger effects while the overall error is dominated by statistics: both are expected to be reduced including the 2004 sample in the analysis. This ongoing work by the NA48/II collaboration has stimulated theoretical interests and a recent paper [7] has pointed out that a form factor should be considered for the decay, so that the form of $\frac{d\Gamma^\pm}{dW}$ comes to be slightly different from equation 2. The effect on the DE measurement is expected to be at the level of some %.

3. The decay of $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$

The decay $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$ is similar to the $K^\pm \rightarrow \pi^\pm \gamma \gamma$, with one of the photons internally converting into a pair of electrons. Both decays can be described in the framework of χ PT, where the lowest order terms are of order p^4 and where loop diagrams contribute predominantly to the amplitude [8]. This leads to a characteristic signature in the $e^+e^- \gamma$ invariant mass, which is preferred to be above $2m_{\pi^+}$ and exhibits a cusp at the $2m_{\pi^+}$ threshold. The loop contributions

are finite, but in the χ PT framework the decay rate also depends on a free parameter \hat{c} , which is a function of several strong and weak coupling constants. Theoretical predictions[9] give values for the branching ratios in the range between $0.9 - 1.7 \times 10^{-8}$, for values of $|\hat{c}| < 2$. These values for $|\hat{c}|$ are preferred by theory and an experimental result based on a small amount of $K^\pm \rightarrow \pi^\pm \gamma \gamma$ confirms that expectation[10].

The NA48/2 collaboration has performed the first observation of the decay and 120 events passing all data analysis cuts were selected, 7.3 ± 1.7 of them estimated as background (see figure 3). With $K^\pm \rightarrow \pi^\pm \pi_D^0$ as normalization channel, The branching ratio is determined to be:

$$BR(K^\pm \rightarrow \pi^\pm e^+ e^- \gamma) = (1.19 \pm 0.12_{stat} \pm 0.04_{syst}) \times 10^{-8}. \quad (5)$$

Using such value for the branching ratio and fitting the shape of the $e^+ e^- \gamma$ spectrum (see figure 4), a preliminary value for the \hat{c} parameter has been extracted:

$$\hat{c} = 0.90 \pm 0.45 \quad (6)$$

where the error is dominated by statistics.

4. Hyperon radiative decays

The $\Xi^0 \rightarrow \Lambda^0 \gamma$ decay asymmetry plays an important role in solving a long standing discrepancy between the Hara theorem[11] and the observed decay asymmetries of weak radiative hyperon decays. The Hara theorem states that the parity violating amplitude of weak radiative hyperon decays vanishes in the SU(3) limit. Accordingly, the decay asymmetries will vanish in this case. Introducing weak breaking of SU(3) symmetry one expects to observe small decay asymmetries. In contrast to this, a large negative decay asymmetry in the weak radiative decay $\Sigma^+ \rightarrow p \gamma$ was measured[12]. To address this observation, models were developed which tried to obtain large decay asymmetries in spite of weak SU(3) breaking. One category consists of pole models, which satisfy the Hara theorem by construction, and approaches based on chiral perturbation theory [13],[14],[15]. They predict negative decay asymmetries for all weak radiative hyperon decays. Vector meson dominance models and calculations based on the quark model on the other hand violate the Hara theorem[16][17]. This second group of models favors a positive decay asymmetry for the channel $\Xi^0 \rightarrow \Lambda^0 \gamma$. Therefore, this decay plays a crucial role in differentiating between the various models.

After having measured the $\Xi^0 \rightarrow \Lambda \gamma$ decay asymmetry from the data collected during a short run in 1999, NA48/I collaboration has now measured this parameter from 2002 data with more than 43 thousands candidates as shown by figure 5.

For the asymmetry measurement the well-known decay asymmetry of the $\Lambda \rightarrow p \pi^-$ decay is exploited. The Λ hyperons are polarized by the parent process $\Xi^0 \rightarrow \Lambda^0 \gamma$ decay asymmetry and by the initial polarization of the Ξ^0 beam. Effectively, one measures the distribution of the angle Θ_Λ between the incoming Ξ^0 (corresponding to the outgoing Λ direction in the Ξ^0 rest frame) and the outgoing proton in the Λ rest frame. After subtracting the background contribution, the ratio of data over a flat MonteCarlo corrects for the detector acceptance. A fit taking into account the initial polarization of the primary Ξ^0 s is then performed (see figure 6) obtaining the following result:

$$\alpha(\Xi^0 \rightarrow \Lambda \gamma) = -0.68 \pm 0.02(stat) \pm 0.06(syst) \quad (7)$$

where the systematic uncertainty is dominated by the modelling of the neutral beam in the MonteCarlo. The result, in agreement with the previous one, clearly prefers models consistent with the pole models satisfying Hara theorem, while, it cannot be easily explained by quark models and models using vector meson dominance.

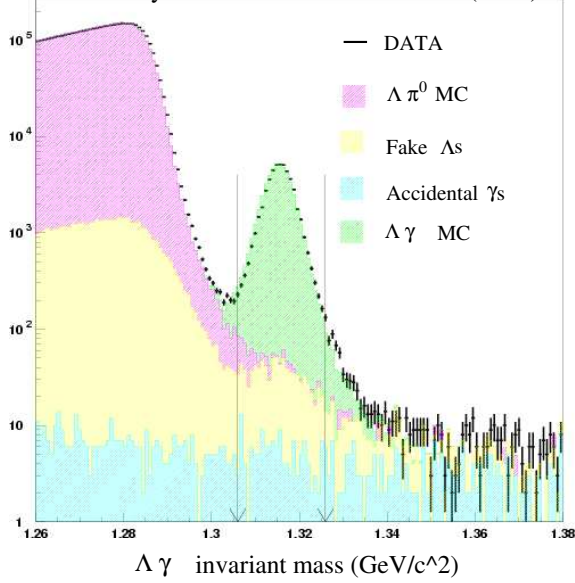


Figure 5. $\Lambda\gamma$ invariant mass for the events passing analysis selection, 43814 candidates lie in the signal region. The main contributions to the background (giving an overall contribution of 0.8% to the final sample) are also shown.

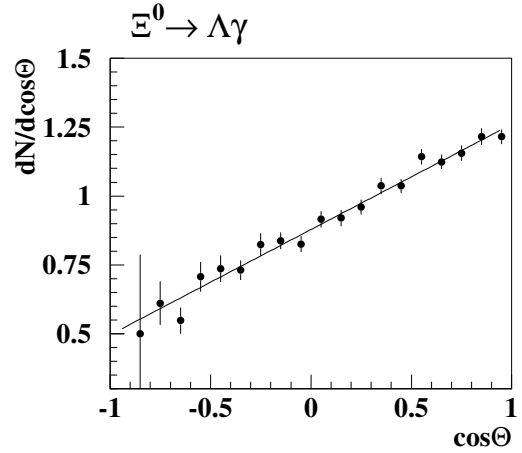


Figure 6. Ratio between background subtracted data over flat MonteCarlo as a function of $\cos\Theta_\Lambda$. The black line corresponds to the best fit giving the measured value of the decay asymmetry.

The first observation of $\Xi^0 \rightarrow \Lambda e^+ e^-$ is also reported, 412 candidates in the signal region have been found, with an estimated background of 15 ± 5 events. The measured branching fraction is[18]:

$$BR(\Xi^0 \rightarrow \Lambda e^+ e^-) = [7.6 \pm 0.4(\text{stat}) \pm 0.4(\text{syst}) \pm 0.2(\text{norm})] \times 10^{-6}, \quad (8)$$

consistent with an internal bremsstrahlung process. The decay asymmetry parameter is measured to be:

$$\alpha(\Xi^0 \rightarrow \Lambda e^+ e^-) = -0.8 \pm 0.2, \quad (9)$$

consistent with the one measured for $\Xi^0 \rightarrow \Lambda\gamma$.

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