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New precise measurements of radiative charged kaon and hyperon decays

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New results in the radiative decay of charged kaons sector are presented by the NA48/2 experiment at CERN: the first measurement of the DE and INT contribution to the decay $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ in the T^{*}_{π} region $0 < T^{*}_{\pi} < 80$ Mev and the first observation of $K^{\pm} \to \pi^{\pm}e^{+}e^{-}\gamma$ decay.
Also new results in the radiative decay of hyperons are presented by NA48/1: the measurement of $\Xi^{0} \to \Lambda\gamma$ decay asymmetry and the first observation of the $\Xi^{0} \to \Lambda e^{+}e^{-}$ decay.

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1. The decay $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$

Presently ChPT 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 $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ in the charged kaon sector.

Three components contribute to the decay amplitude: Inner Bremsstrahlung (IB) if the photon is radiated by the charged pion after a $\pi^{\pm}\pi^{0}$ final state is produced, Direct Emission (DE) from the vertex and interference (INT) between these two. The amplitude of a $K \to \pi\pi\gamma$ 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 ChPT 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 $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ can be parametrized using a Lorentz invariant variable:

$$W^2 = \frac{(P_K^* \cdot P_\gamma^*)(P_\pi^* \cdot P_\gamma^*)}{(m_K m_\pi)^2} \tag{1.1}$$

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

$$\frac{d\Gamma^{\pm}}{dW} \simeq \left(\frac{d\Gamma^{\pm}}{dW}\right)_{IB}\left[1+2\left(\frac{m_\pi}{m_K}\right)^2 W^2|E|cos((\delta_1-\delta_0)\pm\phi)+\left(\frac{m_\pi}{m_K}\right)^4 W^4(|E|^2+|M|^2)\right] \tag{1.2}$$

where $\delta_1 - \delta_0$ is the $\pi\pi$ phase shift difference, ϕ is the CP non conseving phase, E and M are the electric and magnetic DE decay amplitudes. The three terms represent the IB, INT and DE contributions respectively. Although the DE component is hardly observed, due to the dominant IB, it can be isolated kinematically using W. The IB component of the $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ decay was measured by Abrams et al. [5] 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 $K^{\pm} \to \pi^{\pm}\pi^{0}$ and $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays, suppressed in the kinematically background free region, $55MeV < T_\pi^* < 90MeV$. 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. In our experiment we have collected the world largest sample of $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$, resulting into about 220000 events passing data selection cuts. Such data sample is very clean, as shown in Figure 1 although we have decided to accept events also in the low region of T_π^*. Indeed, this region is kinematically accessible to $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays when one of the two photons from the π^0s is lost. The reason for such a complication is that the region at small T_π^* values is more sensitive to DE and INT decay mechanisms. 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

Exp.	year	#events	$BR(DE) \cdot 10^{-6}$
E787 [1]	2000	20K	$4.7 \pm 0.8 \pm 0.3$
E470 [2]	2003	4.5K	$3.2 \pm 1.3 \pm 1.0$
E787 [3]	2005	20K	$3.5 \pm 0.6 \pm 0.35$
E470 [4]	2005	10K	$3.8 \pm 0.8 \pm 0.7$

Table 1: DE experimental results

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

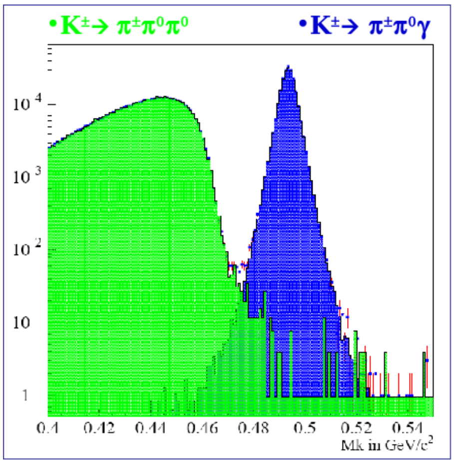

Figure 1: Data - MC comparison of M_K spectrum

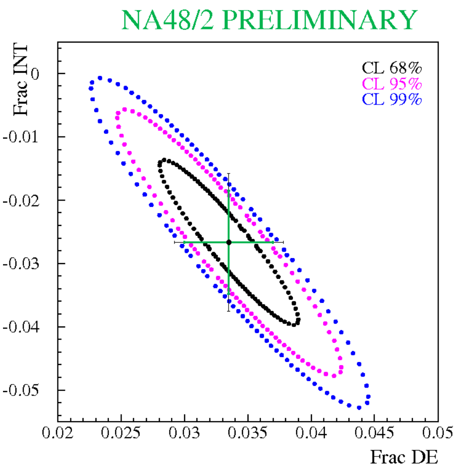

Figure 2: Contour plot for DE and INT components

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 wrt the IB branching ratio in the region $0 < T^*_\pi < 80$ MeV are:

$$Frac(DE) = (3.35 \pm 0.35_{sta} \pm 0.25_{sys})\% \qquad (1.3)$$

$$Frac(INT) = (-2.67 \pm 0.81_{sta} \pm 0.73_{sys})\% \qquad (1.4)$$

All results are preliminary. The present measurement is the first result for a non vanishing interference term in the $K^\pm \to \pi^\pm \pi^0 \gamma$ 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. The work has stimulated theoretical interests and a recent paper [6] has poinetd out that a form factor should be

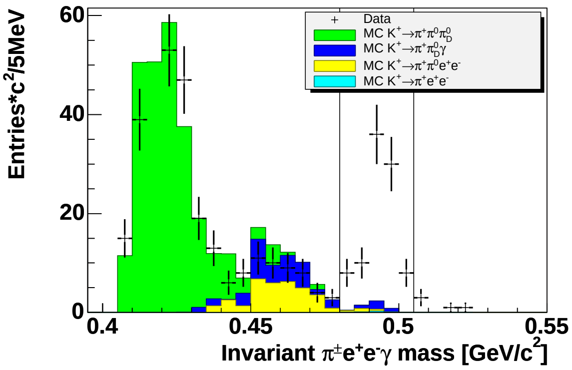

Figure 3: selected signal candidates and background expectation from MC simulation

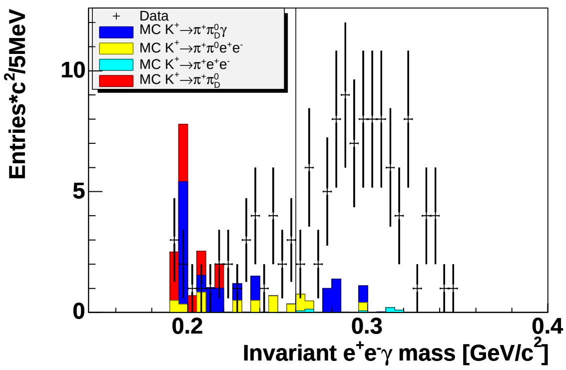

Figure 4: $e^+e^-\gamma$ invariant mass

considered for the decay, so that the form of $\frac{d\Gamma^\pm}{dW}$ comes to be slightly different from 1. The effect on the measurement is expected to be of few percent.

2. The decay of $K^\pm \to \pi^\pm e^+ e^- \gamma$

The decay $K^\pm \to \pi^\pm e^+ e^- \gamma$ is similar to the $K^\pm \to \pi^\pm \gamma\gamma$, with one of the photons internally converting into a pair of electrons. Both decays can be described in the framework of ChPT, where the lowest order terms are of order p^4 and predominantly loop diagrams contribute to the amplitude [7]. 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 diagram is fixed in the ChPT, but depends on a free parameter $\hat{c}$, which is a function of several strong and weak coupling constants. Higher order ChPT calculations on $K^\pm \to \pi^\pm \gamma\gamma$ have been performed, but are model dependent. Also for $K^\pm \to \pi^\pm e^+ e^- \gamma$ theoretical predictions exist [8]. The predicted branching ratios lie in the range between $0.9 - 1.7 \times 10^{-8}$, for values of $|\hat{c}| < 2$ (where an experimental result based on a small amount of $K^\pm \to \pi^\pm \gamma\gamma$ exists [9]). In NA48/2 we performed the first observation of the decay and selected 120 events passing all data analysis cuts, 7.3±1.7 of them estimated as background, see Figure 3. By means of $K^\pm \to \pi^\pm \pi^0_D$, with $\pi^0_D \to e^+e^-\gamma$ as normalization channel, we determined the branching ratio to be

$$BR(K^\pm \to \pi^\pm e^+ e^- \gamma) = (1.19 \pm 0.12_{stat} \pm 0.04_{syst}) \times 10^{-8} \tag{2.1}$$

Afterwords, using such a value for the branching ratio and the shape of the $e^+e^-\gamma$ spectrum, see Figure 4, we extracted the $\hat{c}$ parameter

$$\hat{c} = 0.90 \pm 0.45 \tag{2.2}$$

where the error is dominated by statistics.

3. Hyperon radiative decays

Since their discovery, the precise nature of radiative hyperon decays is still an open question of the theory [12, 13], where reliable techniques to predict their branching ratios and other properties remain elusive. In particular, since SU(3) symmetry is broken only weakly in this regime, weak radiative decays should approximately conserve parity [14], therefore the asymmetries of decay angular distributions should be small. However, results from experiments indicate a relatively large (negative) asymmetry in every mode investigated [15]. A number of models have been proposed to explain this apparent discrepancy [16] and $\Xi^0 \to \Lambda\gamma$ plays a crucial role in differentiating between the groups of models. Here, we report our result for the measurement of the $\Xi^0 \to \Lambda\gamma$ asymmetry:

$$alpha(\Xi^0 \to \Lambda\gamma) = -0.68 \pm 0.02(\text{stat}) \pm 0.06(\text{syst}) \tag{3.1}$$

We also report our first observation of $\Xi^0 \to \Lambda e^+ e^-$ We found 412 candidates in the signal region, with an estimated background of 15 ± 5 events. We determined the branching fraction

$$BR(\Xi^0 \to \Lambda e^+ e^-) = [7.6 \pm 0.4(\text{stat}) \pm 0.4(\text{syst}) \pm 0.2(\text{norm})] \times 10^{-6}, \tag{3.2}$$

consistent with an internal bremsstrahlung process, and the decay asymmetry parameter

$$\alpha(\Xi^0 \to \Lambda e^+ e^-) = -0.8 \pm 0.2, \tag{3.3}$$

consistent with that of $\Xi^0 \to \Lambda\gamma$

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