PROCEEDINGS OF SCIENCE

ChPT tests at NA62

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The NA62 experiment at CERN SpS collected a large sample of charged kaon decays with a low intensity beam and minimum bias trigger conditions in 2007. This allowed measurements of a number of rare decays that are difficult to address in conventional high intensity experiments with highly selective trigger conditions. In particular, large samples of $K^{\pm} \to \pi^{\pm}\gamma\gamma$ and $K^{\pm} \to e^{\pm}\nu\gamma$ decays have been collected, allowing precision tests of the Chiral Perturbation Theory. The status and first results of these analyses are presented.

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1. The NA62 experiment

The first phase of the NA62 experiment exploited the NA48/2 beam line and detector setup[1] with optimizations for $K \to e^{\pm\nu}$ data collection. The beam line of NA48/2 experiment was designed to deliver simultaneously K^+ and K^- 60 GeV/c beam, produced on a beryllium target from SPS primary protons. In NA62 the beam momentum has been moved to (74 ± 2) GeV/c. The beams after being momentum selected and focused by magnetic elements, enter 114 m long vacuum decay volume. The momenta of the charged decay products are measured by a magnetic spectrometer consisting of four drift chambers (DCHs) and a dipole magnet. The resolution reached by the spectrometer in NA62 running condition is $\sigma(p)/p = (1.0 \oplus 0.044p)\%$ (p in GeV/c). A scintillator hodoscope (HOD), located after the spectrometer, produces fast trigger signals and measures the time of charged particles with an offline resolution of 150 ps. The electromagnetic energy deposit of particles is measured by a liquid krypton calorimeter (LKr) with a resolution of $\sigma(E)/E = (3.2/\sqrt{E} \oplus 9/E \oplus 0.42)\%$

2. The $K^\pm \to \pi^\pm\gamma\gamma$ decay

Measurements of radiative non-leptonic kaon decays provide crucial tests for the ability of the Chiral Perturbation Theory (ChPT) to explain weak low energy processes. In the ChPT framework, the $K^\pm(p) \to \pi^\pm(p_3)\gamma(q_1)\gamma(q_2)$ differential decay rate can be parametrized as[3]:

$$\frac{\partial^2\Gamma}{\partial x \partial y} = \frac{m_K}{(8\pi)^3} \cdot \left[z^2 \cdot (|A+B|^2 + |C|^2) + \left(y^2 - \frac{1}{4}\lambda(1,z,r_\pi^2) \right)^2 \cdot (|B|^2 + |D|^2) \right] \tag{2.1}$$

where $z = m_{\gamma\gamma}^2/m_K^2$ and $y = p \cdot (q_1 - q_2)/m_K^2$. The dominant contribution at O(p^4) comes from the loop term $A(z,\hat{c})$, including the pion and kaon loop amplitudes, the B and D terms are zero and the Wess-Zumino-Witten term C accounts for ~10% of the total decay rate. The $\hat{c}$ can be written in terms of parameters of the $\mathscr{L}^4$ weak chiral Lagrangian (N_i)[3]:

$$\hat{c} = \frac{128\pi^2}{3}[3(L_9 + L_{10}) + N_{14} - N_{15} - 2N_{18}]. \tag{2.2}$$

Different combination of the same parameters can be extracted from measurements of many other $K^\pm$ radiative decays: $\pi^\pm e^+ e^- \gamma$ [4], $\pi^\pm\pi^0\gamma$ [5], $\pi^\pm l^+ l^-$ [6][7], $\pi^\pm\pi^0 e^+ e^-$ [8] and their corresponding K_L and K_S decays. Constraining the N_i constants through all these measurements will increase the predictive power of ChPT. Higher order unitarity corrections from $K^\pm \to 3\pi^\pm$ decays, including the main O(p^6) contribution as well as those beyond O(p^6), have been found to contribute significantly to the BR (up to 30-40%) and to the shape of $M_{\gamma\gamma}$ spectrum[3]. The total decay rate is predicted to be $BR(K^\pm \to \pi^\pm\gamma\gamma) \sim 10^{-6}$, with the pole amplitude contributing at the level of 5% or less [3]. The ChPT predictions for the decay spectra, for several values of $\hat{c}$, are presented in Fig. 1: the diphoton mass spectra exhibit a characteristic cusp at twice the pion mass due to the dominant pion loop amplitude $A(z,\hat{c})$. The sensitivity to both the value of $\hat{c}$ and the $O(p^6)$ corrections is high enough to allow significant experimental measurements even with relatively small data samples.

The only $K^\pm \to \pi^\pm\gamma\gamma$ experimental observation published so far is by the BNL E787 experiment [10]:

$$BR(K^\pm \to \pi^\pm\gamma\gamma)_{E787} = (1.1 \pm 0.3 \pm 0.1) \cdot 10^{-6} \qquad \textit{with} \qquad \hat{c} = 1.8 \pm 0.6 \tag{2.3}$$

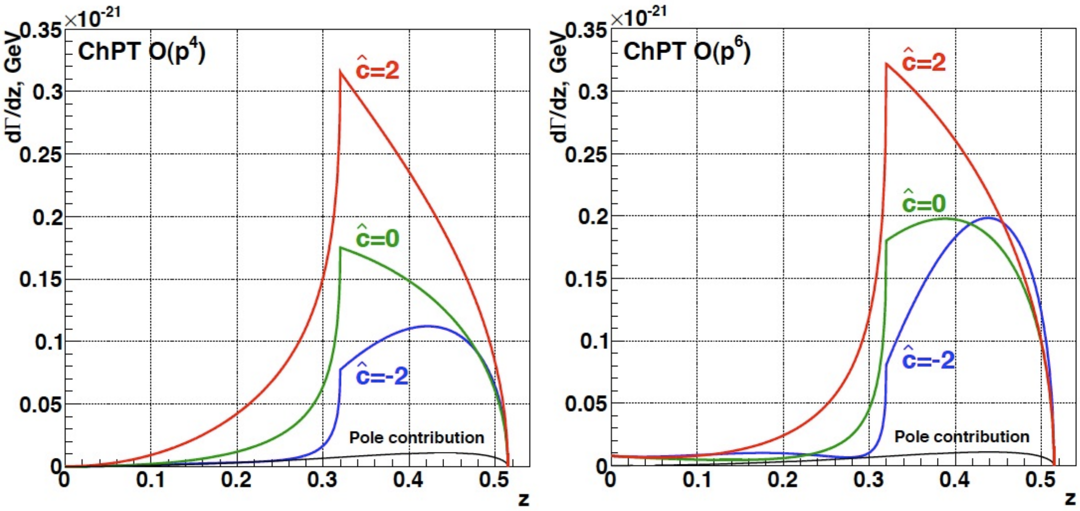

Figure 1: ChPT predictions for the differential rate in terms of z for $O(p^4)$ and $O(p^6)$ parameterizations according to[3], with $\hat{c}$ = 2; 0; -2. The $\hat{c}$-independent pole contribution C is also shown.

based on 31 K^+ decay candidates in the kinematic region 100 MeV/c $<p_\pi<$ 180 MeV/c (p_π is the π^+ momentum in the K^+ rest frame). The value of the BR quoted in eq. 2.3 refers to the entire kinematical range and is obtained with a MC extrapolation using the value 1.8 for $\hat{c}$.

2.1 The data analysis

The new measurements described here have been performed using minimum bias data sets collected during a 3-day special NA48/2 run in 2004 with 60 GeV/c $K^\pm$ beams, and a 3-month NA62 run in 2007 with 74 GeV/c $K^\pm$ beams. The latter set has been collected with a set of downscaled trigger conditions with an effective downscaling factor of about 20. The effective kaon fluxes collected in 2004 and 2007 are similar, but the background conditions and resolution on kinematic variables differ significantly. Signal events are selected in the region z = $(m_{\gamma\gamma}/m_K)^2 > 0.2$ to reject the $K^\pm \to \pi^\pm\pi^0$ background peaking at z = 0.075. The $\pi^\pm\gamma\gamma$ mass spectra, with the MC simulation expectations of the signal and background contributions, are displayed in Fig. 2: 147 (175) decays candidates are observed in the 2004 (2007) data set, with backgrounds contaminations of 12% (7%) from $K^\pm \to \pi^\pm\pi^0(\pi^0)(\gamma)$ decays with merged photon clusters in the LKr calorimeter. The data spectra of the z kinematic variable, together with the signal and background expectations, are displayed in Fig. 3: they clearly exhibit the cusp at the two-pion threshold as predicted by the ChPT. The values of the $\hat{c}$ parameter in the framework of the ChPT $O(p^4)$ and $O(p^6)$ parameterizations according to [3] have been measured by performing likelihood fits to the data. The preliminary results of the fits are presented in Tab.1.

The uncertainties are dominated by the statistical ones while the systematic ones are mainly due to the background estimates uncertainties. The O(p^6) parametrization involves a number of external inputs. In the present analysis, they have been fixed as follows: the polynomial contribution terms are η_1 = 2.06, η_2 = 0.24 and η_3 = -0.26 as suggested in [3], while the $K^\pm \to 3\pi^\pm$ amplitude parameters come from a fit to the experimental data [9]. Along with the separate 2004 and 2007 results, the combined results are also presented in Tab.1

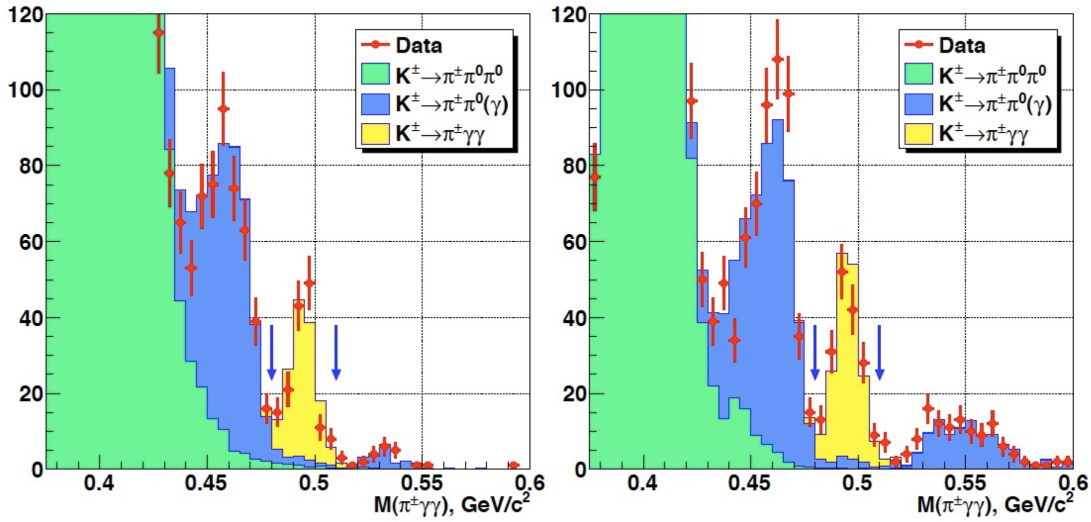

Figure 2: The invariant kaon mass spectrum with MC expectations for signal and backgrounds: on the left 2004 and on the right 2007 data samples. The signal region is within the blue arrows.

Table 1: Preliminary results for the $\hat{c}$ and BR($\pi^+\gamma\gamma$) measurements. The combination takes into account the large positive correlation of the systematic uncertainties for the two measurements. The quoted BR values correspond to the full kinematic range.

	$\hat{c}$ $O(p^4)$ fit	$\hat{c}$ $O(p^6)$ fit	BR $O(p^6)$ fit
2004 data	$1.36 \pm 0.33_{stat} \pm 0.07_{syst}$	$1.67 \pm 0.39_{stat} \pm 0.09_{syst}$	$(0.94 \pm 0.08) \cdot 10^{-6}$
2007 data	$1.71 \pm 0.29_{stat} \pm 0.06_{syst}$	$2.21 \pm 0.31_{stat} \pm 0.08_{syst}$	$(1.06 \pm 0.07) \cdot 10^{-6}$
Combined	$1.56 \pm 0.22_{stat} \pm 0.07_{syst}$	$2.00 \pm 0.24_{stat} \pm 0.09_{syst}$	$(1.01 \pm 0.06) \cdot 10^{-6}$

The measured BR, in agreement with the E787 one, improves the precision of the measurement by a factor $\sim$5. The obtained value of $\hat{c}$, for both the $O(p^4)$ and $O(p^6)$ fits, is in very good agreement with the previous measurement by E787[10]. The same parameter has been already estimated by NA48/2 using the decay $K^\pm \to \pi^\pm e^+ e^- \gamma$, obtaining a compatible result: $\hat{c} = 0.90 \pm 0.45$ [4].

3. The $K^\pm \to e^\pm \nu\gamma$ decay

The $K^\pm \to e^\pm \nu\gamma$ ($K_{e2\gamma}$) process receives two contributions to the total decay amplitude: "Inner Bremsstrahlung" IB, "Structure-Dependent" SD and a term of interference INT. The IB part is pure QED and, to the lowest order, can be predicted by using just the Low theorem. The SD part receives electro-weak and hadronic contributions and is sensitive to the kaon structure itself, in particular for what concerns its effective coupling to the radiative photon. In contrast with most other radiative decays, due to the helicity suppression of the IB, the $K_{e2\gamma}$ SD transition is of the same order of the dominating IB. This is a unique opportunity to perform precise measurements of the vector (F_V) and axial (F_A) form factors.

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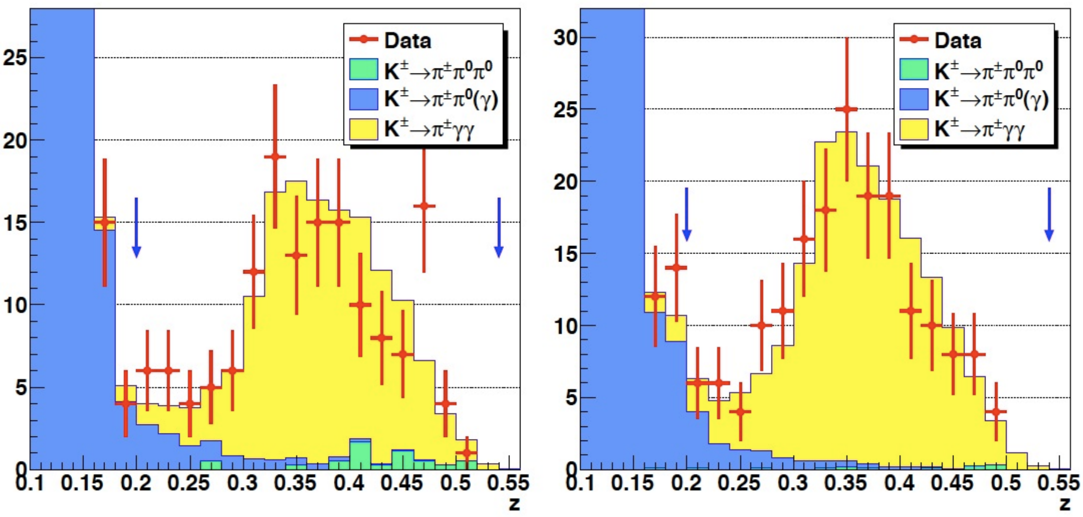

Figure 3: The $z = (m_{\gamma\gamma}/M_K)^2$ spectrum with MC expectations for signal, best fit, and backgrounds: on the left 2004 and on the right 2007 data samples. The signal region, 0.2 < z < 0.52, is within the blue arrows.

The $K_{e2\gamma}$ differential decay rate for the structure dependent part is given by:

$$\frac{\partial^2\Gamma}{\partial x \partial y} = \frac{m_K^5 \alpha G_F^2 |V_{us}|^2}{64\pi^2} \cdot \left[(F_A + F_V)^2 f_{SD+}(x,y) + (F_V - F_A)^2 f_{SD-}(x,y)\right] \tag{3.1}$$

with $x = 2E^*_\gamma/m_K$ and $y = 2E^*_e/m_K$. f_{SD+} and f_{SD-} represent the hadronic structure dependent contributions to the decay rate from SD+ and SD- channels, respectively. Form factors F_V, F_A only depend on p^2, the momentum transferred to the leptonic pair $e^+\nu$. Terms of given helicity SD+, sensitive to $F_V + F_A$ couplings, and SD-, sensitive to $F_V - F_A$ couplings, can be disentangled from kinematical analysis and may lead to a deeper understanding of the kaon structure. The ChPT at $O(p^4)$ predicts constant form factors $F_V(p^2) = F_V(0)$ and $F_A(p^2) = F_A(0)$[11]. At $O(p^6)$ the p^2 or x-dependence of $F_A(p^2)$ is considered negligible, while $F_V(p^2)$ exhibits a linear dependence [12]:

$$F_V(x) = F_V(0) \cdot [1 + \lambda(1-x)]. \tag{3.2}$$

In the light-front quark model (LFQM) the x dependence is more complex [12]. Recent estimate of the parameters together with their uncertainties in the framework of ChPT are reported in [13].

The most recent results of the $(K_{e2\gamma})_{SD+}$ branching ratio and form factors was obtained by the KLOE collaboration based on 1484 candidates in the kinematic region 10 MeV<E^*_γ< 250 MeV and p^*_e>200 MeV[14].

$$BR(K_{e2\gamma})_{SD+} = (9.4 \pm 0.4) \cdot 10^{-6}. \tag{3.3}$$

They also report a fit to the form factors fixing $(F_V - F_A)$ to its ChPT at $O(p^4)$ prediction[14]:

$$F_V(0) + F_A(0) = 0.125 \pm 0.007_{stat} \pm 0.001_{syst} \tag{3.4}$$

$$\lambda = 0.38 \pm 0.20_{stat} \pm 0.02_{syst} \tag{3.5}$$

which confirms at $\sim 2\sigma$ the presence of a slope in the vector form factor F_V. The relatively low precision reached by KLOE on the form factor and a relevant disagreement with the measurement $F_V(0) + F_A(0)$ coming from $K_{\mu 2\gamma}$ motivates further studies.

3.1 $K_{e2\gamma}$ data analisys

A comprehensive study of the process $K_{e2\gamma}$ (SD+) is ongoing in a subsample of the NA62 data collected during 2007 run. A signal acceptance of $\sim 7\%$ is achieved and a data sample of about 10k candidates with a background contamination of $\sim 5\%$ has been isolated. The number of candidates is $\sim$10 times higher than present 1484 candidates by KLOE, with similar BG contamination. The main BG sources have been identified, using MC simulations, to be K_{e3} and $K_{2\pi}$ decay channels. The $M^2_{miss}(e\gamma)$ distribution for the signal and main BG sources is shown in Fig.4. A K_{e3} decay may lead to a fake signal if one photon from the π^0 decay is undetected or if, after a Dalitz decay of the pion, the e^+e^- pair is undetected. A $K_{2\pi}$ decay contributes to the background if one photon from the π^0 decay is undetected and the charged pion is mis-identified as a positron.

A fit has been performed to the measured x spectrum using the distribution expected from the ChPT $O(p^6)$ models with F_A is fixed to $F_A(0)$ and $F_V(0)$ and λ as free parameters. The quality of the fit result is shown in Fig. 4. The estimated form factor parameters with their uncertainties and the correlation coefficients are not yet public. The NA62 measurement aim to a model independent extraction of the theoretical form factors, which will allow validating or falsifying the LFQM, as well as determining the ChPT $O(p^6)$ parameters involved with unprecedented accuracy.

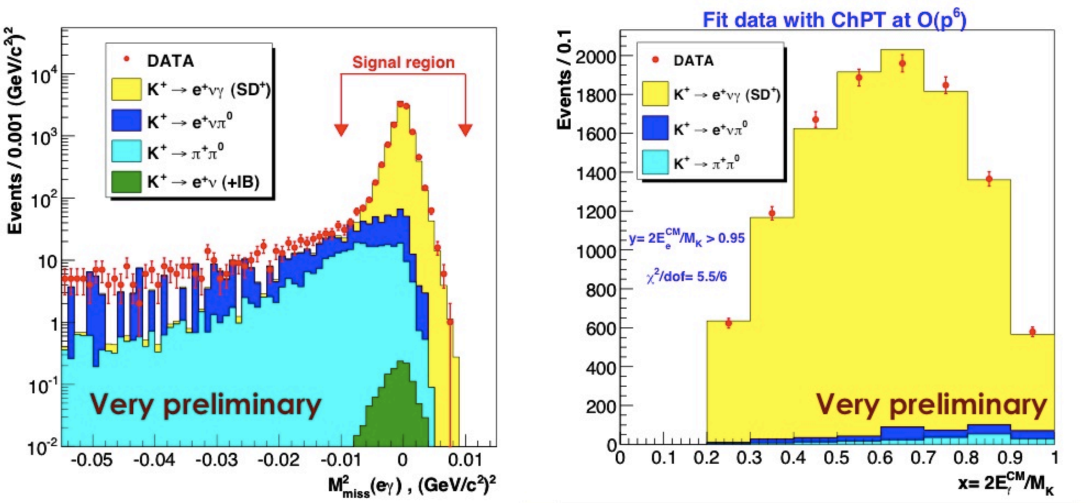

Figure 4: left: M^2_{miss} distribution for the signal and main BG sources. Right: fit to the x spectrum using ChPT $O(p^6)$ MC distribution with $F_V(0)$ and λ as free parameters.

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