

Recent results by the NA48/2 experiment

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The NA48/2 experiment at CERN[?] collected $\sim 18 \cdot 10^9$ charged kaon decays during the years 2003/4. Along with the primary goals of the collaboration, i.e. the measurement of the CP-violating asymmetry in the $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ and $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ decays, the collected data allowed to perform many other interesting analyses. In this paper the results obtained for the $K^\pm \rightarrow e^\pm \nu \pi^+ \pi^-$ (Ke4), $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (Kpi2g) and the $K^\pm \rightarrow \pi^\pm \gamma \gamma$ decays will be reviewed.

1 The NA48/2 experiment

A sketch of the NA48/2 beamline is shown in fig.???. Kaons are produced by impinging 400 GeV protons from the SPS on a Beryllium target and selected through an achromat system in a 60 GeV/c and 3.8% r.m.s. momentum band; afterwards they decay in the ~ 113 m long fiducial region, downstream of which the following detectors are placed (fig.??):

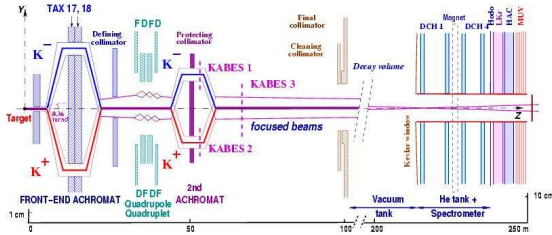


Figure 1: Sketch of the NA48/2 beamline.

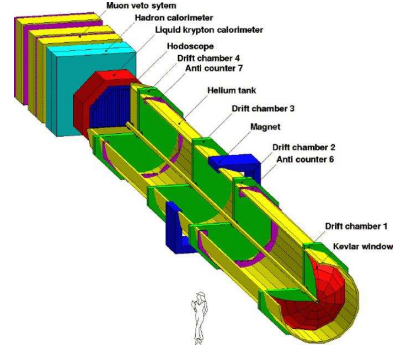


Figure 2: Layout of the NA48/2 detectors.

- the drift chamber (DCH) system, made of 4 octagonal DCHs. Each chamber is made of 4 views of 2 wire planes, staggered by half wire pitch. A magnet, placed between DCH 2 and 3, gives the charged particles a 120 MeV/c transverse momentum kick. The position and momentum resolutions are $\sim 100 \mu\text{m}$ and $\frac{\sigma(P)}{P} = 1.0\% \oplus 0.044 \cdot P(\text{GeV}/c)\%$ respectively.
- the charged hodoscope, made of two planes of 64 plastic scintillator strips. It provides fast trigger conditions ($T_{res} \sim 150$ ps) and yields the time measurement for charged tracks.
- the liquid krypton calorimeter (LKr), made of 13248 2×2 cm² cells, defined by Cu-Be-Co 127 cm long ribbons. The 27 radiation lengths and small Molière radius allow an excellent

$$\text{energy resolution: } \frac{\sigma_E}{E} = \frac{0.032}{\sqrt{E(\text{GeV})}} \oplus \frac{0.09}{E(\text{GeV})} \oplus 0.0042.$$

Other detectors include: a TPC detector aiming at measuring the kaons' momentum and direction, a neutral hodoscope made of scintillating fibers, a veto system of 7 rings of iron and scintillator placed along the decay region, a hadronic calorimeter and a muon veto.

2 Ke4 form factors and phase shift

2.1 Theory and analysis

The Ke4 is a four body decay, which implies five independent variables; the Cabibbo-Maksymowicz variables $S_e, S_\pi, \theta_e, \theta_\pi, \phi$ [?] are commonly used. The hadronic part of the amplitude can be written as:

$$\begin{aligned} \langle \pi^+ \pi^- | A^\lambda | K^+ \rangle = & \frac{1}{M_K} (F(p_{\pi^+} + p_{\pi^-})^\lambda + G(p_{\pi^+} - p_{\pi^-})^\lambda + R(p_e + p_\nu)^\lambda + \\ & + \frac{H}{M_K^2} \epsilon^{\lambda\mu\rho\sigma} (p_{\pi^+} + p_{\pi^-} + p_e + p_\nu)_\mu (p_{\pi^+} + p_{\pi^-})_\rho (p_{\pi^+} - p_{\pi^-})_\sigma) \end{aligned}$$

The form factors F, G and H can be expanded in partial waves:

$$F = F_s e^{i\delta_s} + F_p e^{i\delta_p} \cos \theta_\pi + \dots \quad G = G_p e^{i\delta_g} + \dots \quad H = H_p e^{i\delta_h} + \dots \quad (1)$$

The form factor R is suppressed in Ke4 decays (but is relevant in $K\mu 4$). Neglecting d wave terms and assuming the same phase for every coefficient, four coefficients (F_s, F_p, G_p, H_p) are left, which can in turn be expanded in powers of $q^2 = (\frac{S_\pi}{4m_\pi^2} - 1)$ and $\frac{S_e}{4m_\pi^2}$:

$$F_s = f_s + f'_s q^2 + f''_s q^4 + f'_e \frac{S_e}{4m_\pi^2} + \dots \quad (2)$$

$$F_p = f_p + f'_p q^2 + \dots \quad G_p = g_p + g'_p q^2 + \dots \quad H_p = h_p + h'_p q^2 + \dots \quad (3)$$

The selection of the events was performed requiring two opposite sign pions ($E/p < 0.8$, $p_\pi > 5$ GeV/c^a) and one electron or positron ($0.9 < E/p < 1.1$, $p_e > 3$ GeV/c). Time cuts, as well as minimum distance cuts among tracks and clusters, were applied. The background (from $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ followed by a $\pi \rightarrow e\nu$ decay or with a misidentified pion, or from $K^\pm \rightarrow \pi^\pm \pi^0 (\pi^0)$ with a Dalitz decay $\pi^0 \rightarrow e^+ e^- \gamma$ and photon(s) lost) has been checked directly on data, using the so called wrong-sign events and so avoiding to heavily rely on the MC.

2.2 Fitting procedure and form factor extraction

15000 iso-populated bins were used in the five-dimensional phase space, the average number of events/bin being 48 for the K^+ and 27 for the K^- sample. Form factor values are extracted by minimizing an estimator well suited for small numbers. Since no branching fraction has been measured in this analysis, only relative form factors $\frac{F_p}{F_s}, \frac{G_p}{F_s}, \frac{H_p}{F_s}$ and the phase shift $\delta = \delta_s - \delta_p$ are accessible. The F_s^2 dependence from $M_{\pi\pi}$ and $M_{e\nu}$ is extracted using the relative normalization data/MC and then deconvoluted from the other relative form factors, whose residual dependence by $M_{\pi\pi}, M_{e\nu}$ is finally investigated. The results of the form factor fits are (value \pm stat \pm syst):

$$f'_s/f_s = 0.152 \pm 0.007 \pm 0.005 \quad f''_s/f_s = -0.073 \pm 0.007 \pm 0.006 \quad f'_e/f_s = 0.068 \pm 0.006 \pm 0.007 \quad (4)$$

$$f_p/f_s = -0.048 \pm 0.003 \pm 0.004 \quad g_p/f_s = 0.868 \pm 0.010 \pm 0.010 \quad h'_p/f_s = 0.089 \pm 0.017 \pm 0.013 \quad (5)$$

$$h_p/f_s = -0.398 \pm 0.015 \pm 0.008 \quad (6)$$

^aE/p is the ratio between the energy in the EM calorimeter and the momentum measured by the spectrometer.

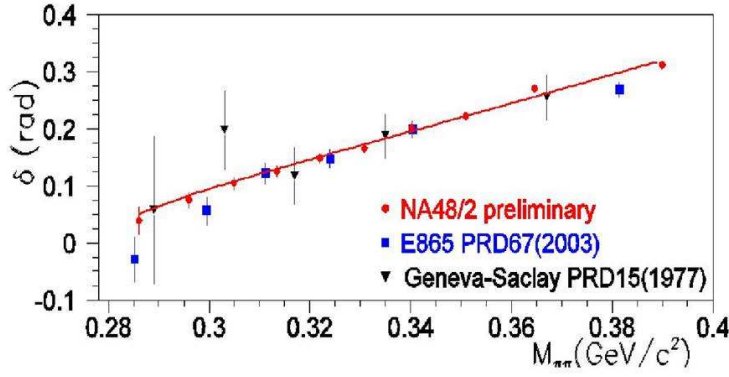


Figure 3: Phase shift δ from NA48/2 compared to the measurements of other experiments ^{??}.

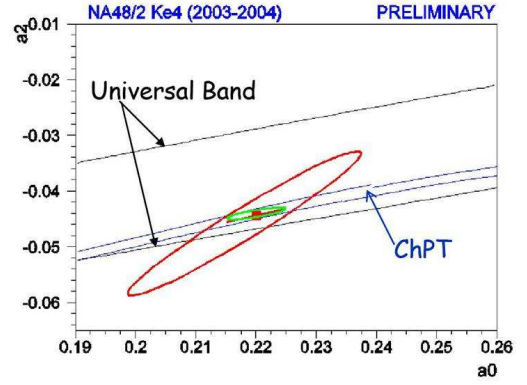


Figure 4: The a_2 - a_0 plane.

2.3 The δ phase shift and scattering length extraction

The extraction of pion scattering lengths from δ requires the use of Roy equations [?] and data at intermediate energies [?]. Besides performing a 2 parameter fit on a_0^0 and a_2^0 , the Universal Band approach, corresponding to a 1-dimensional fit of δ with a fixed relation between a_0^0 and a_2^0 , is also used, while an additional constraint comes from ChPT [?], see fig. ^{??}. Isospin breaking and radiative corrections are included. The phase shift fit is shown in fig. ^{??}; the estimation of pion scattering lengths yields:

$$a_0 = 0.2199 \pm 0.0215_{exp} \pm 0.003t_{th} \quad a_2 = -0.0430 \pm 0.0083_{exp} \pm 0.0028t_{th} \quad (7)$$

$$a_0 = 0.2206 \pm 0.0049_{exp} \pm 0.0018_{syst} \pm 0.0064t_{th} \quad (\text{ChPT constraint}) \quad (8)$$

3 $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (Kpi2g) decay

The decay rate as a function of $W = \sqrt{(P_K \cdot P_\gamma)/(M_K M_{\pi^+})}$ can be written as:

$$\frac{d\Gamma}{dW} \simeq \left(\frac{d\Gamma}{dW}\right)_{IB} [1 + 2\left(\frac{m_\pi}{m_K}\right)^2 W^2 |E| \cos((\delta_1 - \delta_0) \pm \phi) + \left(\frac{m_{\pi^+}}{m_K}\right)^4 W^4 (|E|^2 + |M|^2)] \quad (9)$$

where three contributions, respectively representing the inner bremsstrahlung (IB), the direct emission (DE) and the interference (INT) part of the decay, can be distinguished; the estimation of the INT and DE part represents the main goal of this analysis. The selection of the $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ decay requires at least 1 track with $E/p < 0.85$ and 3 clusters in the final state. Several BG channels were analyzed and reduced, the most important being the $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ decay; the probability of photon mistagging was seen to be at 1% level, while the residual BG is at 0.1% level of the DE part. The estimation of the DE and INT part is performed using the variable $W = \sqrt{(P_K \cdot P_\gamma)/(M_K M_\pi)}$ in the interval $0.2 < W < 0.9$, where events from the IB, DE and INT parts distribute differently. The relative weights minimizing the DATA/MC ratio are determined, the fit function being $W_{DATA} = (1-A-B) \cdot W_{IB} + A \cdot W_{DE} + B \cdot W_{INT}$ with A,B free parameters (see fig. ^{??}). The final results on 2003/4 data are:

$$A_{DE}(0 < W < 1) = (3.32 \pm 0.15_{stat} \pm 0.14_{syst})\%, \quad (10)$$

$$A_{INT}(0 < W < 1) = (-2.35 \pm 0.35_{stat} \pm 0.39_{syst})\% \quad (11)$$

where the systematics are dominated by trigger efficiency. This represents the first measurement of the INT component of the decay so far. Two tests of CP violation using $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ data were also performed, the first computing the difference in the decay rate between positive and negative events (and using $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ events to compute the kaon flux) and the second fitting the W spectrum. Both of them yielded results compatible with no CPV.

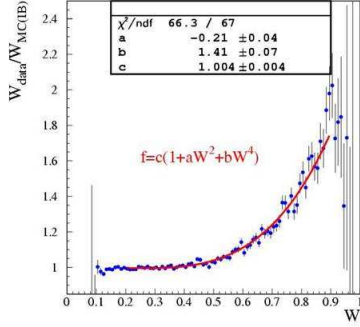


Figure 5: Fit of the W variable allowing the determination of INT and DE parts in Kpi2g decay.

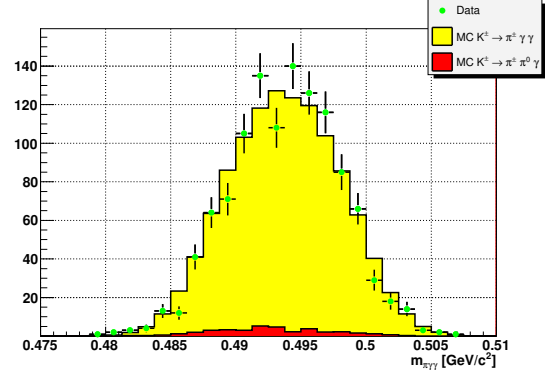


Figure 6: Distribution of reconstructed kaon mass for $K^\pm \rightarrow \pi^\pm \gamma \gamma$ events.

4 $K^\pm \rightarrow \pi^\pm \gamma \gamma$ decay

The differential decay rate of the $K^\pm \rightarrow \pi^\pm \gamma \gamma$ channel can be written as:

$$\frac{d^2\Gamma}{dydz} = \frac{m_{K^+}}{(8\pi)^3} [z^2(|A+B|^2 + |C|^2) + (y^2 - \frac{1}{4}\lambda(1, r_\pi^2, z))^2(|B|^2 + |D|^2)] \quad (12)$$

where $y = P \cdot (q_1 - q_2) / M_K^2$, $z = (q_1 + q_2) / M_K^2 = M_{\gamma\gamma}^2 / M_K^2$ and P , q_1 , q_2 are respectively the pion and the two photon four-momenta. A , B , C and D only depend on z and on the free parameter \hat{c} , which is a function of several strong and weak coupling constants. Depending on the \hat{c} value, the BR theoretical estimation and the shape of the $m_{\gamma\gamma}$ distribution sizably change. Corrections at $\mathcal{O}(p^6)$ order in ChPT can increase BR by 30-40%, depending on the \hat{c} value?

The event selection is performed by requiring at least one track with $E/p < 0.8$ and two LKr clusters. The reconstructed kaon mass, shown in fig. ??, is required to be within ± 0.02 GeV/c^2 from its PDG value. 1164 events are selected, with $\sim 3\%$ estimated BG, mostly from $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ decays. The \hat{c} value used for the MC generation is 2.0, which yields a good agreement with data. The preliminary BR result, using $K^\pm \rightarrow \pi^\pm \pi^0$ as normalization, is:

$$BR(K^\pm \rightarrow \pi^\pm \gamma \gamma) / BR(K^\pm \rightarrow \pi^\pm \pi^0) = (1.07 \pm 0.04_{stat} \pm 0.08_{syst}) \cdot 10^{-6} \quad (13)$$

Future tasks include the \hat{c} measurement using a model-independent BR estimation.

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