Recents 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 $K^\pm \to \pi^\pm\pi^+\pi^-$ and $K^\pm \to \pi^\pm\pi^0\pi^0$ decays, the collected data allowed to perform many other interesting analyses. In this paper the results obtained for the $K^\pm \to e^\pm\nu\pi^+\pi^-$ (Ke4), $K^\pm \to \pi^\pm\pi^0\gamma$ (Kpi2g) and the $K^\pm \to \pi^\pm\gamma\gamma$ 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 $\sim$113 m long fiducial region, downstream of which the following detectors are placed (fig.**??**):

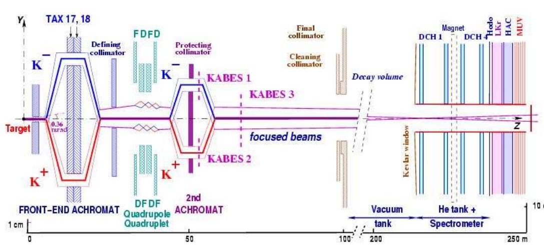

Figure 1: Sketch of the NA48/2 beamline.

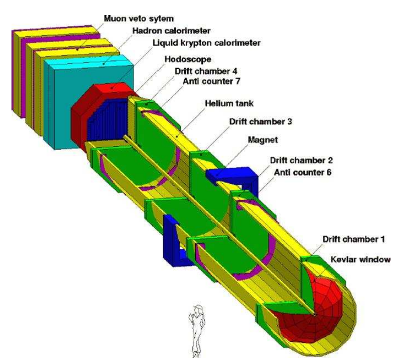

Figure 2: Layout of the NA48/2 detectors.

- 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 $\sim 100\mu$m and $\frac{\sigma(P)}{P} = 1.0\% \oplus 0.044 \cdot P(GeV/c)\%$ 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 $2{\times}2$ cm^2 cells, defined by Cu-Be-Co 127 cm long ribbons. The 27 radiation lengths and small Molière radius allow an excellent

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

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_π, θ_e, θ_π, ϕ [?] are commonly used. The hadronic part of the amplitude can be written as:

$$< \pi^+\pi^-|A^\lambda|K^+ >= \frac{1}{M_K}(F(p_{\pi^+}+p_{\pi^-})^\lambda + G(p_{\pi^+}-p_{\pi^-})^\lambda + R(p_e+p_\nu)^\lambda +$$

$$+\frac{H}{M^2{}_K}\epsilon^{\lambda\mu\rho\sigma}(p_{\pi^+}+p_{\pi^-}+p_e+p_\nu)_\mu(p_{\pi^+}+p_{\pi^-})_\rho(p_{\pi^+}-p_{\pi^-})_\sigma)$$

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

$$F = F_s e^{i\delta_s} + F_p e^{i\delta_p}\cos\theta_\pi + ... \qquad G = G_p e^{i\delta_g} + ... \qquad H = H_p e^{i\delta_h} + ... \tag{1}$$

The form factor R is suppressed in Ke4 decays (but is relevant in Kμ4). 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 $\frac{S_e}{4m_\pi{}^2}$:

$$F_s = f_s + f_s' q^2 + f_s'' q^4 + f_e' \frac{S_e}{4m_\pi^2} + ... \tag{2}$$

$$F_p = f_p + f_p' q^2 + ... \qquad G_p = g_p + g_p' q^2 + ... \qquad H_p = h_p + h_p' q^2 + ... \tag{3}$$

The selection of the events was performed requiring two opposite sign pions (E/p<0.8, p_π >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 $K^\pm \to \pi^\pm\pi^+\pi^-$ followed by a $\pi \to e\nu$ decay or with a misidentified pion, or from $K^\pm \to \pi^\pm\pi^0(\pi^0)$ with a Dalitz decay $\pi^0 \to e^+e^-\gamma$ 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±stat±syst):

$$f_s'/f_s = 0.152 \pm 0.007 \pm 0.005 \quad f_s''/f_s = -0.073 \pm 0.007 \pm 0.006 \quad f_e'/f_s = 0.068 \pm 0.006 \pm 0.007 \tag{4}$$

$$f_p/f_s = -0.048 \pm 0.003 \pm 0.004 \quad g_p/f_s = 0.868 \pm 0.010 \pm 0.010 \quad g_p'/f_s = 0.089 \pm 0.017 \pm 0.013 \tag{5}$$

$$h_p/f_s = -0.398 \pm 0.015 \pm 0.008 \tag{6}$$

[a] E/p is the ratio between the energy in the EM calorimeter and the momentum measured by the spectrometer.

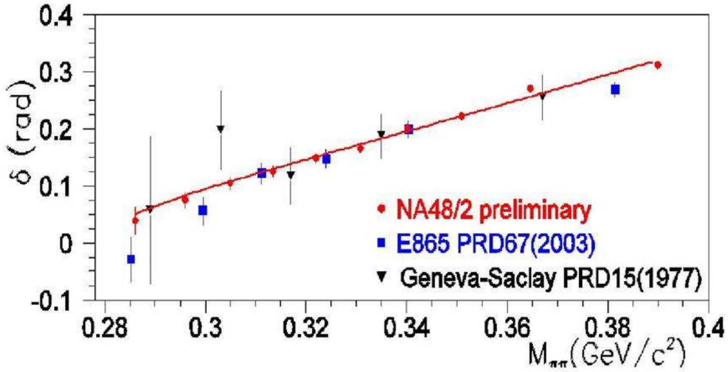

Figure 3: Phase shift δ from NA48/2 compared to the measurements of other experiments ? ?.

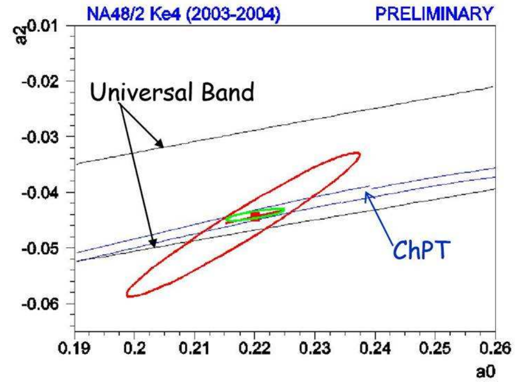

Figure 4: The a_2-a_0 plane.

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:

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

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

3 $K^{\pm} \to \pi^{\pm}\pi^0\gamma$ (Kpi2g) decay

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

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

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 $K^{\pm} \to \pi^{\pm}\pi^0\gamma$ 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 $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ 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)·W_{IB}+A·W_{DE}+B·W_{INT} with A,B free parameters (see fig. **??**). The final results on 2003/4 data are:

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

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

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 $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ data were also performed, the first computing the difference in the decay rate between positive and negative events (and using $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ events to compute the kaon flux) and the second fitting the W spectrum. Both of them yielded results compatible with no CPV.

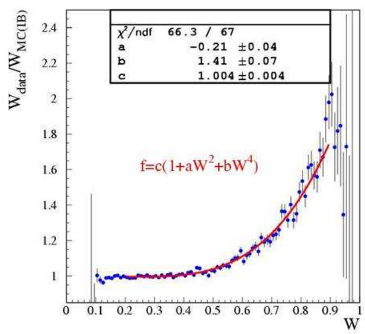

Figure 5: Fit of the W variable allowing the determination of INT and DE parts in Kpi2g decay.

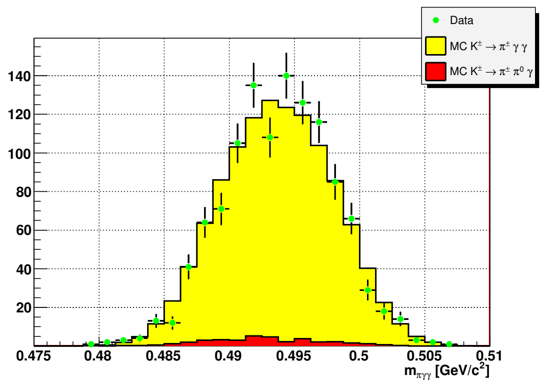

Figure 6: Distribution of reconstructed kaon mass for $K^{\pm} \to \pi^{\pm}\gamma\gamma$ events.

4 $K^{\pm} \to \pi^{\pm}\gamma\gamma$ decay

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

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

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 ĉ, which is a function of several strong and weak coupling constants. Depending on the ĉ 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 ĉ 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 ∼3% estimated BG, mostly from $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ decays. The ĉ value used for the MC generation is 2.0, which yields a good agreement with data. The preliminary BR result, using $K^{\pm} \to \pi^{\pm}\pi^{0}$ as normalization, is:

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

Future tasks include the ĉ measurement using a model-independent BR estimation.

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