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Recent results and prospects from NA48/2: $K^\pm \to \pi^0 l^\pm \nu$ and $K^\pm \to \pi^+\pi^- e^\pm \nu$, $K^\pm \to \pi^0\pi^0 e^\pm \nu$ decays

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Abstract

In 2003-2004 the NA48/2 Collaboration at CERN collected a large sample of $K^\pm$ decays. Using data taken with minimal trigger conditions, a sample of 2.5×10^6 $K^\pm \to \pi^0\mu^\pm\nu$ and 4.0×10^6 $K^\pm \to \pi^0 e^\pm \nu$ events was recorded, and allows precise measurements of the decay form factors. This report describes the event selection and the fitting procedure, and gives a preliminary result for the form factors in various parameterizations. In addition, with the full data sample collected, more than one million $K^\pm \to \pi^+\pi^- e^\pm \nu$ and about 45000 $K^\pm \to \pi^0\pi^0 e^\pm \nu$ decays has been analysed. An improved determination of the branching ratio and high precision form factor measurements for $K^\pm \to \pi^+\pi^- e^\pm \nu$, and a preliminary result for the branching ratio of $K^\pm \to \pi^0\pi^0 e^\pm \nu$ are presented in this paper. Future prospects include the observation of several thousands decays in similar muonic modes that will be studied at the NA62 experiment.

Keywords: NA48, Kaon, Semileptonic decays, Form factors, Branching ratio

1. Beam and detector

Simultaneous K^+ and K^- beams were produced by 400 GeV/c primary protons delivered by the CERN SPS and impinging on a beryllium target. The NA48/2 beamline selected kaons with a momentum range of (60 ± 3) GeV/c. A detailed description of the beamline and of the detector is available in [1]. The momentum of charged particles from $K^\pm$ decays was measured by a magnetic spectrometer consisting of four drift chambers (DCH1-DCH4) and a dipole magnet between DCH2 and DCH3. Each chamber has eight planes of sense wires, two horizontal, two vertical and two along each of the orthogonal 45 degrees directions. The spectrometer is located in a tank filled with helium at atmospheric pressure and separated from the decay volume by a Kevlar window. A 16 cm diameter alluminium vacuum tube centred on the beam axis runs the length of the spectrometer through central holes in the window, drift chambers and calorimeters. Charged particles are magnetically deflected in the horizontal plane by an angle corresponding to a transverse momentum kick of 120 MeV/c. The momentum resolution of the spectrometer is $\sigma(p)/p = 1.02\% \oplus 0.044\% p$ (p in GeV/c). The magnetic spectrometer is followed by a scintillator hodoscope. A liquid Krypton calorimeter (LKr) is used to measure the energy of electrons and photons. The calorimeter is 27 X_0 thick and has an energy resolution $\sigma(E)/E = 0.032/\sqrt{E} \oplus 0.09/E \oplus 0.0042$ (E in GeV). The space resolution for single electromagnetic showers can be parameterised as $\sigma_x = \sigma_y = 0.42/\sqrt{E} \oplus 0.06$ cm for each transverse coordinate x, y. For the selection of muons, a muon veto system (MUV) was essential to distinguish muons from pions. It consisted of three planes of alternating horizontal and vertical scintillator strips. Each plane was shielded by a 80 cm thick iron wall. The inefficiency of the system was at the level of one per mil for muons with momentum greater than 10 GeV/c and the time resolution was below 1 ns.

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2. The $K^\pm \to \pi^0 l^\pm \nu$ decays

Semileptonic kaon decays (denoted as K_{l3} in the following, with $l = e, \mu$) provide the most accurate way and free of theoretical uncertainties, to measure the CKM matrix element $|V_{us}|$ [2]. To extract $|V_{us}|$, the knowledge of the decay form factors is crucial: since the form factors determine the Dalitz plot structure, both the detector acceptance (needed to measure the decay rate) and the phase space integral (needed to derive $|V_{us}|$ from the decay rate) heavily depend on the form factors. The hadronic matrix element of K_{l3} decays is described by two dimensionless form factors $f_\pm(t)$, which depend on the squared four-momentum $t = (p_K - p_\pi)^2$ transferred to the lepton system. The $K^\pm$ decays are usually described in terms of the vector form factor f_+ and the scalar form factor f_0 defined as [2]:

$$f_0(t) = f_+(t) + \frac{t}{m_K^2 - m_\pi^2} f_-(t).$$

The functions f_+ and f_0 are related to the vector (1^-) and scalar (0^+) exchange to the lepton system, respectively. The contribution of f_- can be neglected in $Ke3$ decays since it is proportional to the lepton mass squared. By construction $f_0(0) = f_+(0)$. Since $f_+(0)$ is not directly measurable, it is customary to normalise all form factors to this quantity, so that:

$$\bar{f}_+(t) = \frac{f_+(t)}{f_0(t)} \; ; \; \bar{f}_-(t) = \frac{f_-(t)}{f_0(t)}.$$

To describe the form factors, two different parameterisations are used in this report. Widely known and most used is the Taylor expansion, called quadratic parameterisation in the following:

$$\bar{f}_{+,0}(t) = 1 + \lambda'_{+,0}\frac{t}{m_\pi^2} + \frac{1}{2}\lambda''_{+,0}\frac{t^2}{m_\pi^4}$$

where λ' and λ'' are the slope and the curvature of the form factors, respectively. The disadvantage of this parameterisation is related to the strong correlations between the parameters and the absence of a direct physical interpretation. To reduce the number parameters and to add a physical motivation, the pole parameterisation is used:

$$\bar{f}_+(t) = \frac{M_V^2}{M_V^2 - t} \; ; \; \bar{f}_0(t) = \frac{M_S^2}{M_S^2 - t}.$$

Here, the dominance of a single vector (V) or scalar (S) resonance is assumed and the corresponding pole mass M_V or M_S is the only free parameter.

The data used for the form factor analysis presented here were collected in 2004 during a dedicated run with a special trigger setup which required one or more tracks in the magnetic spectrometer and an energy deposit of at least 10 GeV/c in the electromagnetic calorimeter. Besides, the intensity of the beam was lowered and the momentum spread was reduced. The NA48 detector measures only the charged lepton and the two photons from the π^0 decay, while the neutrino leaves the detector unseen. To select the decay, one track in the magnetic spectrometer and at least two clusters in the electromagnetic calorimeter were required. The track had to be inside the geometrical acceptance of the detector, and needed a good reconstructed decay vertex, proper timing and a momentum greater than 5 GeV/c in case of electrons. For muons the momentum needed to be greater than 10 GeV/c to ensure high MUV efficiency. To identify the track as a muon, an associated hit in the MUV system and $E/p < 0.2$ was required, where E is the energy deposited in the LKr calorimeter and p is the track momentum. For electrons a range of $0.95 < E/p < 1.05$ and no associated hit in the MUV system were required. The neutral pions were reconstructed by two photon clusters in the LKr calorimeter, with an energy $E_\gamma > 3$ GeV/c, well isolated from any track hitting the calorimeter, and in time with the track in the spectrometer. Finally, the missing mass squared was required to satisfy $m^2_{miss} < (10MeV/c^2)^2$ under a $K^\pm$ hypothesis.

For $K^\pm_{e3}$, the only significant background is from $K^\pm \to \pi^\pm\pi^0$. A cut in the transverse momentum of the event reduces this background to less than 0.1% while losing only about 3% of the signal. For $K^\pm_{\mu3}$ the background from $K^\pm \to \pi^\pm\pi^0$ with $\pi^\pm$ decaying in flight is suppressed by using a combined requirement on the invariant mass $m(\pi^\pm\pi^0)$ (under $\pi^\pm$ hypothesis) and on the π^0 transverse momentum. This cut reduces the contamination to 0.5%, but causes a loss of statistics of about 24%. Another background source is $K^\pm \to \pi^\pm\pi^0\pi^0$ events with $\pi^\pm$ decaying in flight and one π^0 not reconstructed. Its contribution is estimated to be only about 0.1% and therefore no specific cut was applied. To extract the form factors, two-dimension fits to the Dalitz plot densities $\rho(E^*_l, E^*_\pi)$ are performed:

$$\rho(E^*_l, E^*_\pi) = \frac{d^2N(E^*_l, E^*_\pi)}{dE^*_l dE^*_\pi}$$

$$\approx Af_+^2(t) + Bf_+(t)(f_+(t) - f_0(t))\frac{m_K^2 - m_\pi^2}{t}$$

$$+C[(f_+(t) - f_0(t))\frac{m_K^2 - m_\pi^2}{t}]^2$$