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Test of Chiral Perturbation Theory with K_{e4}^{+-} and K_{e4}^{00} decays at NA48/2

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The poster presents the analysis of large samples of kaon decays collected in 2003 – 2004 by the NA48/2 collaboration at the CERN SPS in the charged pion K_{e4}^{+-} ($K^{\pm} \to \pi^{+}\pi^{-}e^{\pm}\nu$) and neutral pion K_{e4}^{00} ($K^{\pm} \to \pi^{0}\pi^{0}e^{\pm}\nu$) modes. In the charged pion mode, form factors have been extensively studied from a sample of more than one million decays and a preliminary branching ratio measurement, improved by a factor of three, is reported here. In the neutral pion mode, a sample of ~ 45000 decays has been analyzed and provides a new branching ratio value with $1-2\%$ precision, a factor of ten improvement with respect to the current knowledge. Form factor measurements in both modes contribute to the study of low energy QCD and are powerful tests of Chiral Perturbation Theory predictions.

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1. The semileptonic K_{e4} decays

The most general K_{e4} decay is fully described by the five kinematic Cabibbo-Maksymowicz variables [1]: two invariant masses $S_\pi = M^2_{\pi\pi}$ and $S_e = M^2_{e\nu}$ and three angles θ_π, θ_e and ϕ. The hadronic current is described by form factors which can be developed in a partial wave expansion as suggested in [2]. Limiting the expansion to S- and P-waves and considering a unique phase δ_p for all P-wave form factors, two axial $(F,\ G)$ and one vector (H) complex form factors contribute to the transition amplitude: $F = F_s\ e^{i\delta_s} + F_p\ e^{i\delta_p} cos\theta_\pi,\ G = G_p\ e^{i\delta_p},\ H = H_p\ e^{i\delta_p}$. Four real form factors (F_s, F_p, G_p and H_p) and a single phase difference ($\delta = \delta_s - \delta_p$) are then measured, together with their energy variation with S_π and S_e. In the neutral pion mode K^{00}_{e4}, the variables θ_π and ϕ are irrelevant and the form factors reduce to the single F_s value due to Bose statistics.

2. Beam and detector setup

Two simultaneous $K^\pm$ beams were produced by 400 GeV protons from the CERN/SPS impinging on a beryllium target. Opposite charge particles with a central momentum of 60 GeV/c and a momentum band of $\pm3.8\%$ were selected and focused ~ 200 m downstream at the first spectrometer chamber. The magnetic spectrometer consists of a dipole magnet surrounded by two sets of drift chambers. The momentum of charged decay products (p) is measured with a relative precision of $\sim 1\%$ for 10 GeV/c tracks. It is followed by a scintillator hodoscope consisting of two planes segmented into horizontal and vertical strips achieving a very good ~ 150 ps time resolution. A liquid krypton calorimeter (LKr), 27 radiation length thick, is used to measure electromagnetic deposits (E) and to identify electrons through their E/p ratio (the energy and transverse position resolutions are $\sim 1\%$ and ~ 1.5 mm (resp.) for 10 GeV showers). A two-level trigger logic selects and flags event with a high efficiency for both K_{e4} topologies. A detailed description is available in [3].

3. Branching ratio measurements

The K_{e4} branching ratios (BR) are measured relative to abundant normalization modes $(K_{3\pi})$ recorded concurrently by the same trigger logic:

$$\mathrm{BR}(K_{e4}) = (N_s - N_b)/N_n \cdot (A_n\ \varepsilon_n)/(A_s\ \varepsilon_s) \cdot \mathrm{BR}(K_{3\pi}), \tag{3.1}$$

where N_s, N_b, N_n are the numbers of signal, background and normalization candidates, and A_s, ε_s (A_n, ε_n) are the geometrical acceptances and trigger efficiencies for the signal and the normalization samples, respectively. The dominant background comes from $K_{3\pi}$ events with misidentification of one charged pion as an electron.

The charged pion K^{+-}_{e4} BR is measured relative to the $K^\pm \to \pi^+\pi^-\pi^\pm$ mode (BR= $(5.59 \pm 0.04)\%$) with similar topology in term of number of charged particles. A very large sample over one million charged pion K_{e4} decays has been analyzed [4] to measure $\pi\pi$ scattering lengths with a few percent precision. Form factors values have been obtained relative to a single overall factor f_s which will be determined from the BR value. Out of $\sim 2.3 \times 10^{10}$ total recorded triggers, 1.11×10^6 K_{e4} candidates, 10545 background events (same-charge pions events) and 1.9×10^9

normalization candidates have been selected. The geometrical acceptances (based on a GEANT3 simulation) have similar values of 18.22% (K_{e4}) and 24.18% ($K_{3\pi}$). They make use of our best knowledge of the signal and normalization matrix elements [4]. Trigger efficiencies ($\sim 98\%$) are measured using minimum bias control triggers and found stable with time.

The neutral pion K_{e4}^{00} BR is measured relative to the $K^{\pm} \to \pi^0\pi^0\pi^{\pm}$ mode (BR= $(1.761 \pm 0.022)\%$). Final states have similar topologies of one charged particle and two π^0 reconstructed from four decay photons detected in the LKr. The analysis selected $\sim 71 \times 10^6$ normalization events, 44909 K_{e4} candidates and 598 background events estimated from control regions. Geometrical acceptances include our best knowledge of the normalization mode [5] which describes accurately the observed cusp effect in the S_π distribution. They amount to 1.77% (K_{e4}) and 4.11% ($K_{3\pi}$). Trigger efficiencies vary with data taking conditions between 92 and 98% but the ratio $\varepsilon_n/\varepsilon_s$ is stable with time and close to unity.

4. Results and summary

Preliminary results, inclusive of $K_{e4\gamma}$ decays, are obtained at improved precision:

$$\mathrm{BR}(K_{e4}^{+-}) = (4.279 \pm 0.004_{\mathrm{stat}} \pm 0.016_{\mathrm{syst}} \pm 0.031_{\mathrm{ext}}) \times 10^{-5},\ \text{PDG value} = (4.09 \pm 0.10) \times 10^{-5},$$
$$\mathrm{BR}(K_{e4}^{00}) = (2.595 \pm 0.012_{\mathrm{stat}} \pm 0.024_{\mathrm{syst}} \pm 0.032_{\mathrm{ext}}) \times 10^{-5},\ \text{PDG value} = (2.2 \pm 0.4) \times 10^{-5},$$

where systematic errors include uncertainties on acceptance, resolution, beam geometry, particle identification, trigger efficiencies and radiative corrections. External errors stem from the normalization mode BR uncertainties and are now the dominant errors. The F_s form factor variations with $q^2 (= S_\pi/4m_{\pi^+}^2 - 1)$ are shown in Fig.1. A quadratic behaviour is present in both modes for ($q^2 > 0$) and a deficit of events is observed below the $2m_{\pi^+}$ threshold ($q^2 < 0$) in the neutral pion mode as can be expected from final state charge exchange scattering ($\pi^+\pi^- \to \pi^0\pi^0$) [6].

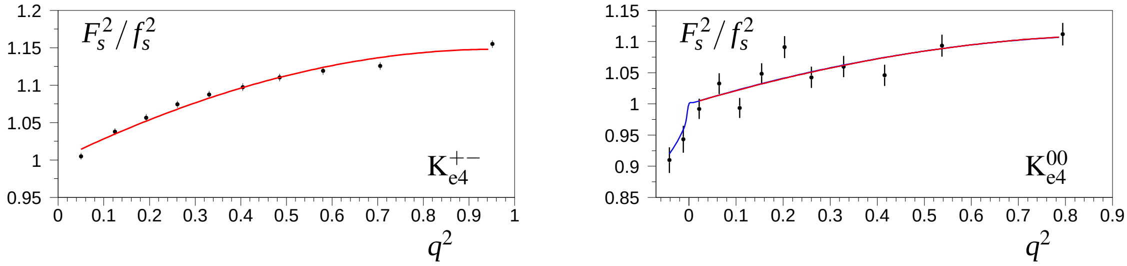

Figure 1: F_s^2/f_s^2 relative form factor measurements function of q^2 in the charged pion mode K_{e4}^{+-} (**Left**) and the neutral pion mode K_{e4}^{00} (**Right**). Red lines are degree-2 polynomial fits to the data (statistical errors only) for $q^2 > 0$. The blue line includes one-loop theoretical prescription with negative interference below threshold and is in good agreement with the observed spectrum.

From large samples of K_{e4}^{+-} and K_{e4}^{00} decay candidates with low background contamination of order 1%, new measurements of the branching fractions, inclusive of $K_{e4\gamma}$ decays, have been performed at improved precision and will dominate the next world average values. In the final analyses, the simultaneous determination of the decay form factors will provide very precise inputs to theoretical studies, in particular in the determination of Low Energy Constants (LEC) of Chiral Perturbation Theory (ChPT).

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