Recent results from the NA48 experiment at CERN: CP violation and CKM parameter $|V_{us}|$

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Abstract. Several recent results from the NA48 experiment are presented: a measurement $|\eta_{+-}|$, search for CP violating phenomena in $K^\pm \to 3\pi$ decays, and a measurement of $|V_{us}|$.

1. Introduction

The NA48 series of experiments represents the long-term CERN program in experimental kaon physics. During the 10 years of operation since 1997, several physics programs were accomplished. The experimental setup has been upgraded in the course of operation; its principal components are a kaon beam line and a vacuum decay volume followed by a magnetic spectrometer consisting of four drift chambers, a trigger scintillator hodoscope, a liquid krypton electromagnetic calorimeter, and a muon detector [1].

The present paper contains a number recent precise measurements based on various data sets: 1) measurement of the indirect CP violation parameter $|\eta_{+-}|$ with $K_L \to \pi^+\pi^-$ decays; 2) measurement of the direct CP violating Dalitz plot slope asymmetries A_g in $K^\pm \to 3\pi^\pm$ and $K^\pm \to \pi^\pm\pi^0\pi^0$ decays; 3) measurement of the CKM matrix element $|V_{us}|$ based on partial widths of the semileptonic $K^\pm \to \pi^0 l^\pm \nu$ decays.

2. Measurement of the indirect CP violation parameter $|\eta_{+-}|$

The interest in the measurement of the parameter $|\eta_{+-}| = A(K_L \to \pi^+\pi^-)/A(K_S \to \pi^+\pi^-)$ stems, in particular, from the fact that precision measurements of this value by KTeV and KLOE experiments published in 2004 and 2006, respectively, were disagreement with the previous world average by 5%, or more the four standard deviations.

The NA48 measurement if $|\eta_{+-}|$ [2] is based on the data taken during 2 days of dedicated running in 1999. The directly measured quantity is the ratio of the decay rates $R = \Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_L \to \pi e\nu)$; these decays are characterized by similar signatures involving two reconstructed tracks of charged particles. Then $|\eta_{+-}|$ is computed as

$$|\eta_{+-}| = \sqrt{\frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)}} = \sqrt{\frac{\mathrm{BR}(K_L \to \pi^+\pi^-)}{\mathrm{BR}(K_S \to \pi^+\pi^-)} \cdot \frac{\tau_{KS}}{\tau_{KL}}}. \quad (1)$$

In this approach the K_L and K_S lifetimes τ_{KL} and τ_{KS}, and the branching fractions $\mathrm{BR}(K_L \to \pi e\nu)$ and $\mathrm{BR}(K_S \to \pi^+\pi^-)$ are external inputs taken from the best single measurements.

The data sample contains about 80×10^6 2-track triggers. Event selection is rather similar for the $K_L \to \pi^+\pi^-$ and $K_L \to \pi e \nu$ modes. A crucial difference is electron vs pion identification based on the ratio of energy deposition in the electromagnetic calorimeter to track momentum measured by the spectrometer. Identification efficiency was measured and corrected for.

Samples of 47×10^3 $K_L \to \pi^+\pi^-$ and 5.0×10^6 $K_L \to \pi e \nu$ candidates were selected, with about 0.5% background contamination in each. Acceptance corrections and background subtraction were performed by Monte Carlo simulation. Trigger efficiencies were measured directly with the data and corrected for. The most relevant systematic uncertainties come from precision of simulation of kaon energy spectrum, precision of radiative corrections, and precision of trigger efficiency measurement. The final result is

$$\Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_L \to \pi e \nu) = (4.835 \pm 0.022_{stat.} \pm 0.016_{syst.}) \times 10^{-3}. \quad (2)$$

This leads, subtracting the $K_L \to \pi^+\pi^-\gamma$ direct emission contribution, but retaining the inner bremsstrahlung contribution, to

$$\mathrm{BR}(K_L \to \pi^+\pi^-) = (1.941 \pm 0.019) \times 10^{-3}. \quad (3)$$

Finally, the CP violating parameter is computed according to (1) to be

$$|\eta_{+-}| = (2.223 \pm 0.012) \times 10^{-3}. \quad (4)$$

The result in in agreement with the recent KLOE and KTeV measurements, while in contradiction to the world average as of 2004.

3. Measurement of the direct CP violation parameter A_g in $K^\pm \to 3\pi$ decays

The $K^\pm \to \pi^\pm\pi^+\pi^-$ and $K^\pm \to \pi^\pm\pi^0\pi^0$ decays are among the most promising processes in kaon physics for a search for CP violating phenomena. The $K^\pm \to 3\pi$ matrix element squared is conventionally parameterized by a polynomial expansion

$$|M(u,v)|^2 \sim 1 + gu + hu^2 + kv^2, \quad (5)$$

where g, h, k are the so called linear and quadratic Dalitz plot slope parameters ($|h|, |k| \ll |g|$), and the two Lorentz invariant kinematic variables u and v are defined as

$$u = \frac{s_3 - s_0}{m_\pi^2}, \quad v = \frac{s_2 - s_1}{m_\pi^2}, \quad s_i = (P_K - P_i)^2, \ i = 1,2,3; \quad s_0 = \frac{s_1 + s_2 + s_3}{3}. \quad (6)$$

Here m_π is the charged pion mass, P_K and P_i are the kaon and pion four-momenta, the indices $i = 1, 2$ correspond to the two pions of the same electrical charge, and the index $i = 3$ to the pion of different charge. A non-zero difference Δg between the slope parameters g^+ and g^- describing the decays of K^+ and K^-, respectively, is a manifestation of direct CP violation expressed by the corresponding slope asymmetry

$$A_g = (g^+ - g^-)/(g^+ + g^-) \approx \Delta g/(2g). \quad (7)$$

The above slope asymmetry is expected to be strongly enhanced with respect to the asymmetry of integrated decay rates. A recent full next-to-leading order ChPT computation [3] predicts A_g to be of the order of 10^{-5} within the SM. Calculations involving processes beyond the SM [4, 5] allow a wider range of A_g, including substantial enhancements up to a few 10^{-4}.

A measurement of the quantity A_g was performed with a record data sample collected in 2003–04 with simultaneous K^+ and K^- beams [6]. The measurement method exploits cancellations of major systematic effects due to simultaneous beams and regular inversions of magnetic fields in the beam line and setup. The samples of events selected are 3.11×10^9 $K^\pm \to \pi^\pm\pi^+\pi^-$ candidates, and 9.13×10^7 $K^\pm \to \pi^\pm\pi^0\pi^0$ candidates, practically background-free.

The CP violating charge asymmetries of the linear slope parameter of the Dalitz plot of the $K^\pm \to \pi^\pm\pi^+\pi^-$ and $K^\pm \to \pi^\pm\pi^0\pi^0$ decays were found to be

$$\begin{array}{lcl} A_g^c & = & (-1.5 \pm 1.5_{stat.} \pm 1.6_{syst.}) \times 10^{-4} = (-1.5 \pm 2.2) \times 10^{-4}, \\ A_g^n & = & (1.8 \pm 1.7_{stat.} \pm 0.6_{syst.}) \times 10^{-4} = (1.8 \pm 1.8) \times 10^{-4}. \end{array} \quad (8)$$

The archived precision is more than an order of magnitude better that those of the previous measurements. The results do not show evidences for large enhancements due to non-SM physics, and can be used to constrain extensions of the SM predicting large CP violating effects.

4. Measurement of the CKM parameter $|V_{us}|$ with the $K^\pm \to \pi^0 l^\pm \nu$ decays

Precise measurements of the CKM matrix parameter $|V_{us}|$ are of interest for tests of CKM unitarity. The $K_{l3}^\pm$ decay rates, including the internal bremssrahlung process, is given by [7]

$$\Gamma(K_{l3(\gamma)}) = \frac{G_F^2 m_K^5}{384\pi^3} S_{EW} |V_{us}|^2 |f_+(0)|^2 I_K (1 + \delta_K), \quad (9)$$

where $f_+(0)$ is a form factor at $q^2 = 0$, $S_{EW} = 1.0232$ is a short distance electroweak correction, I_K is the phase space integral depending on form factors, $(1 + \delta_K)$ is a long-distance correction.

The analysis is based on a measurement of the ratios $\mathrm{BR}(K^\pm \to \pi^0 e^\pm \nu)/\mathrm{BR}(K^\pm \to \pi^\pm\pi^0)$ and $\mathrm{BR}(K^\pm \to \pi^0 \mu^\pm \nu)/\mathrm{BR}(K^\pm \to \pi^\pm\pi^0)$ using the data collected during 3 days of a dedicated run in 2003 [8]. The data samples are 87×10^3 K_{e3} candidates with 0.02% background, and 77×10^3 $K_{\mu 3}$ candidates with 0.2% background. The following partial widths are measured:

$$\begin{array}{lcl} \mathrm{BR}(K_{e3}) & = & 0.05168 \pm 0.00019_{stat.} \pm 0.00008_{syst.} \pm 0.00030_{norm.}, \\ \mathrm{BR}(K_{\mu 3}) & = & 0.03425 \pm 0.00013_{stat.} \pm 0.00006_{syst.} \pm 0.00020_{norm.}. \end{array} \quad (10)$$

Here the last (dominating and correlated) uncertainties are due to precision of the external input $\mathrm{BR}(K_{2\pi})$. The following values of $|V_{us}| f_+(0)$ were computed from K_{e3} and $K_{\mu 3}$ decays:

$$\begin{array}{lcll} |V_{us}| f_+(0) & = & 0.2193 \pm 0.0012, & [K_{e3}] \\ |V_{us}| f_+(0) & = & 0.2177 \pm 0.0013. & [K_{\mu 3}] \end{array} \quad (11)$$

Here the dominating contribution to the uncertainty comes from the long-distance corrections. Combining these results assuming $\mu - e$ universality and using $f_+(0) = 0.961 \pm 0.008$ [7], it is obtained:

$$|V_{us}| = 0.2277 \pm 0.0013 \pm 0.0019_{theor.}, \quad (12)$$

where the second and largest uncertainty owes to the precision of $f_+(0)$ computation. The above measurement is found to be consistent with unitarity of the CKM mixing matrix [8].

Conclusions

A number of recent kaon measurements by the NA48 collaboration at CERN were presented. The achieved precisions are similar to or better than the best previous ones.

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