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SYMMETRY TESTS IN NA48 WITH KAONS

Matthias Behler[1]
Institut für Physik, Johannes Gutenberg-Universtität Mainz
55099 Mainz, Germany
email: Matthias.Behler@uni-mainz.de

Abstract

The main goal of the NA48 experiments at the CERN SPS was the search for direct CP violation (CPV) in kaon decays. Two results of this search will be presented. In the neutral kaon sector the parameter η_{+-} was determined to $|\eta_{+-}| = (2.223 \pm 0.012) \cdot 10^{-3}$ using a sample of about 47000 $K_L \to \pi^+\pi^-$ and five million $K_L \to \pi^\pm e^\mp \nu$. In the charged kaon sector NA48/2 measured the asymmetry A_g of the linear slope parameter g in the Dalitz plot of $K^\pm \to 3\pi$ decays. The results are $A_g^c = (-1.5 \pm 2.1) \cdot 10^{-4}$ using $3.11 \cdot 10^9$ $K^\pm \to \pi^\pm\pi^+\pi^-$ decays and $A_g^n = (1.8 \pm 1.8) \cdot 10^{-4}$ using $9.13 \cdot 10^7$ $K^\pm \to \pi^\pm\pi^0\pi^0$ decays. Here, no evidence for direct CP violation at the order of 10^{-4} has been found.

1 Experimental set-up

The data for the η_{+-} measurement were taken during a dedicated run in 1999 with a pure K_L beam produced by a 450 GeV primary proton beam impinging on a beryllium target. The neutral beam, after passing the final collimator about 100 m downstream the target, entered the 90 m long decay volume which was followed by the NA48 detector. In 2003 and 2004, two simultaneous focused kaon beams of opposite charge, with a momentum of (60 ± 3) GeV were used to measure the asymmetry of $K^\pm \to 3\pi$ decays.

The main detector components are a magnetic spectrometer and a Liquid Krypton Calorimeter with tower read-out. The magnetic spectrometer, consisting of four drift chambers and a dipole magnet located between the second and third chamber, has a momentum resolution of about 1% and a spatial resolution of 100 μm. The calorimeter is an almost homogeneous ionization chamber with an active volume of 7 m^3 and 27 X_0 thickness. It fully contains electromagnetic showers up to 100 GeV and has an energy resolution of about 1% for 20 GeV photons, and a spatial resolution of about 1 mm. A more detailed description can be found in [1].

[1]On behalf of the NA48 and NA48/2 collaborations.

2 CP violation parameter η_{+-}

The observable η_{+-} is related to the parameters of indirect and direkt CPV ($\eta_{+-} = \varepsilon + \varepsilon'$) and defined as the amplitude ratio of the neutral kaons decaying into two charged pions: $\eta_{+-} = A(K_L \to \pi^+\pi^-)/A(K_S \to \pi^+\pi^-)$. The interest in η_{+-} was aroused by recent KTeV and KLOE measurements [2, 3] which disagreed with the previous world average by more than four standard deviations.

The analysis is based on 47000 $K_L \to \pi^+\pi^-$ and five million $K_L \to \pi^\pm e^\mp \nu$ decays [4]. The selection requires good 2-track events and additional cuts to suppress the dominant background. The ratio E/p, where E is the energy deposited in the calorimeter and p is the measured track momentum in the spectrometer, is used to separate both decays (Fig 1).

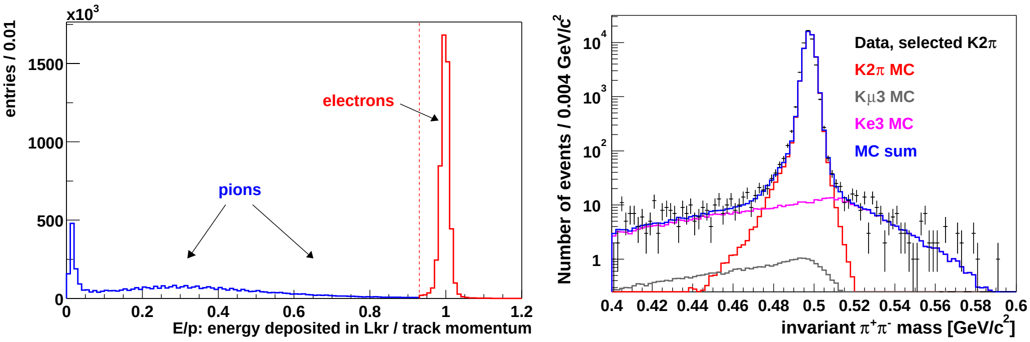

Figure 1: The E/p distribution for K_{e3} events (left) and the invariant $\pi^+\pi^-$ mass for $K_L \to \pi^+\pi^-$ candidates (right).

The ratio of both decay rates after all corrections is

$$\frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^\pm e^\mp \nu)} = (4.835 \pm 0.022_{stat} \pm 0.016_{syst}) \cdot 10^{-3}. \quad (1)$$

Using this ratio and subtracting the contribution of the CP conserving direct emission process $K_L \to \pi^+\pi^-\gamma(\mathrm{DE})$, while including the CP violating inner bremsstrahlung component $K_L \to \pi^+\pi^-\gamma(\mathrm{IB})$, we determined the branching ratio of $K_L \to \pi^+\pi^-$ to

$$\mathrm{BR}(K_L \to \pi^+\pi^-) = (1.941 \pm 0.019) \cdot 10^{-3}. \quad (2)$$

Finally, we calculated η_{+-} using the kaon lifetimes and the branching ratio of $K_S \to \pi^+\pi^-$:

$$|\eta_{+-}| = \sqrt{\frac{\mathrm{BR}(K_L \to \pi^+\pi^-)}{\mathrm{BR}(K_S \to \pi^+\pi^-)} \cdot \frac{\tau_{K_S}}{\tau_{K_L}}} = (2.223 \pm 0.012) \cdot 10^{-3}. \quad (3)$$

The results are in good agreement with recent measurements by KTeV and KLOE and all three experiments contradict the 2004 PDG value.

3 CP violation in $K \to 3\pi$ decays

The $K \to 3\pi$ decays are usually described in terms of two Dalitz variables u and v, depending on the kaon and pion four-momentum P_i and the charged pion mass m_π with $s_i = (P_K - P_i)^2, i = 1,2,3$ and $s_0 = \frac{1}{3}(s_1 + s_2 + s_3)$:

$$u = (s_3 - s_0)/m_\pi^2, \quad v = (s_1 - s_2)/m_\pi^2. \tag{4}$$

The indices $i = 1,2$ correspond to the even pions (same charge) and the index $i = 3$ to the odd pion. The matrix element can be expressed as a polynomial expansion of u and v with the Dalitz plot parameters g, h, and k:

$$|\mathcal{M}(u,v)|^2 \propto 1 + gu + hu^2 + kv^2, \tag{5}$$

with $|h|, |k| \ll |g|$. Complementary with ε'/ε, the CP observable in the charged kaon sector is the asymmetry

$$A_g = (g^+ - g^-)/(g^+ + g^-) \approx \Delta g/(2g) \tag{6}$$

of the linear slope parameters g of K^+ and K^-. Since there is no mixing in charged kaon decays, any non-zero value of A_g reflects evidence for direct CPV. SM predictions for the charged asymmetry lay in the range $10^{-6} - 10^{-5}$ [5], while calculations involving processes beyond the SM allow a range of A_g up to 10^{-4} [6].

The measurement is based on the comparison of the u distributions of K^+ and K^-. Due to the regular inversions of the magnetic fields in the beam line and the spectrometer, four ratios $R_{ij}(u)$ of the u distributions can be defined:

$$R_{ij}(u) = \frac{N^+(u)}{N^-(u)} \propto 1 + \frac{\Delta g \cdot u}{1 + gu + hu^2}. \tag{7}$$

The index $i = U\,(D)$ refers to a configuration in which K^+ runs through the upper (lower) beam path in the achromatic magnet sets, while $j = S\,(J)$ refers to the spectrometer magnet polarity in which positive particles are deflected to the right (left) (towards the Saleve (Jura) mountain). In each single ratio most detector acceptance effects as well as variations in the response are canceled due to the two charged superimposed beams. However, fake asymmetries caused by the spectrometer magnet or the beam line cancel only in the quadruple ratio

$$R_4(u) = R_{US}(u) \cdot R_{UJ}(u) \cdot R_{DS}(u) \cdot R_{DJ}(u) \propto \left(1 + \frac{\Delta g \cdot u}{1 + gu + hu^2}\right)^4 \tag{8}$$

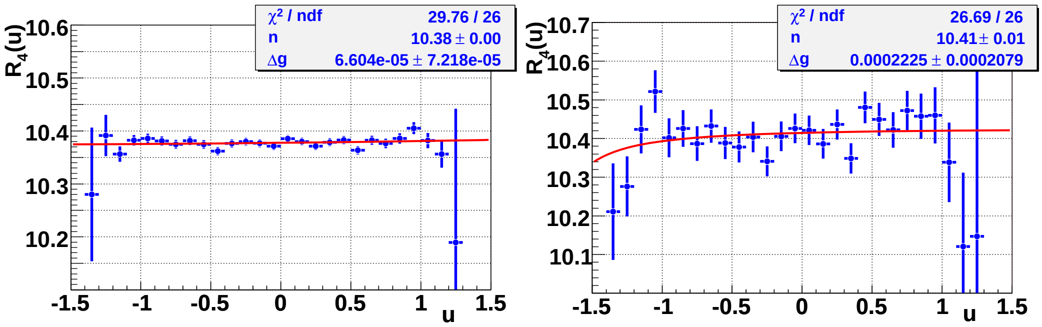

Figure 2: The E/p distribution for K_{e3} events (left) and the invariant $\pi^+\pi^-$ mass for $K_L \to \pi^+\pi^-$ candidates (right).

which is finally fitted to extract Δg (Fig. 2). The full 2003 and 2004 data contains $3.11 \cdot 10^9$ $K^\pm \to \pi^\pm\pi^+\pi^-$ and $9.13 \cdot 10^7$ $K^\pm \to \pi^\pm\pi^0\pi^0$ decays. Using the Dalitz plot slope g^c, recently measured by NA48/2 [7], for the charged mode and the PDG value of g^n for the neutral mode the extracted asymmetries from thess data sets are

$$\begin{aligned} A_g^c &= (-1.5 \pm 1.5_{stat} \pm 0.9_{trig} \pm 1.1_{syst}) \cdot 10^{-4}, \\ A_g^n &= (1.8 \pm 1.7_{stat} \pm 0.5_{syst}) \cdot 10^{-4}. \end{aligned} \tag{9}$$

This is an improvement in accuracy over the previous measurements by more than one order of magnitude. The results are compatible with the SM predictions, i.e. no evidence for direct CP violation at the order of 10^{-4} has been found.

References

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