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Measurement of $\pi\pi$ scattering lengths in Kaon decay by NA48/2

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Abstract. In kaon decays the measurement of $\pi\pi$ scattering lengths (a_0 and a_2) are accessible mainly through the study of kinematical properties in two decay modes. The classic one is based on the analysis of the form factors in the $K^{\pm} \rightarrow \pi^+\pi^-e^{\pm}\nu$ (K_{e4}). Thanks to the absence of other hadrons in the final state the $\pi\pi$ interaction can be analyzed in terms of variation of phase shift with the $\pi\pi$ invariant mass. The preliminary results on a partial set of ~ 670000 $K^{\pm}$ will be discussed. The second way to evaluate the $\pi\pi$ scattering lengths is based on the accurate study of $K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$ Dalitz plot, in which the strong rescattering process $\pi^+\pi^- \rightarrow \pi^0\pi^0$ introduces a singularity in the shape of the distribution. The preliminary result based on $\sim 50 \cdot 10^6$ $K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$ decays is in good agreement with the measurement in K_{e4}.

1. Experimental setup

The NA48/2 experiment beam line has been designed to measure the CP violating charged asymmetry in the $K \rightarrow 3\pi$ decay [1]. Simultaneous positive and negative kaons beams are produced in the same beryllium target by impinging 400 GeV protons from the CERN/SPS accelerator. The momentum range of (60 ± 3) GeV/c is selected, for both beams, in the first "achromat" and a complex system of magnets allows to have superimposed and focused beams $\sim$ 200 m downstream, at the end of the $\sim$ 100 m long decay region. A schematic view of the beam line can be found in [1]. Both K^+ and K^- decays are collected in the same NA48 detectors, described elsewhere [2]. The K_{e4} analysis is essentially based on the magnetic spectrometer, consisting of a magnet dipole and two sets of two drift chambers with a momentum resolution of $\sigma(p)/p = (1.0 + 0.044 \cdot p)\%$ (with p in GeV/c). The $K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$ analysis uses the electromagnetic calorimeter to identify the gammas produced by the π^0 decay. The E.M. calorimeter has $\sim$ 27 radiation lengths of liquid krypton (LKr) with a resolution of $\sigma(E)/E = (3.2/\sqrt{E} \oplus 9.0/E \oplus 0.42)\%$ (with E in GeV).

2. K_{e4} decay analysis

The K_e4 kinematics is fully described using the 5 Cabibbo-Maksymowicz variables [3] : the dilepton and dipion invariant mass and the three angles Θ_π, Θ_e and Φ, as defined in fig.1. Thanks to these variables the two axials (F,G) and one vectorial (H) form factors that contribute to the transition amplitude can be written in terms of a partial wave expansion [4]:

$$F = F_s e^{i\delta_s} + F_p e^{i\delta_p} + ..., \quad G = G_p e^{i\delta_p} + ..., \quad H = H_p e^{i\delta_p} + ...$$

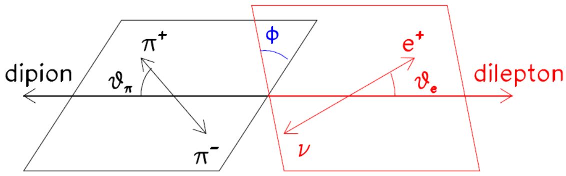

Figure 1. Topology of the K_{e4} decay and defininition of the Cabibbo-Maksymowicz variables.

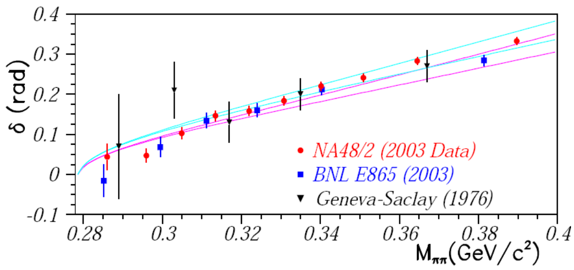

Figure 2. Phase shift as a function of $M_{\pi\pi}$. The bands corresponds to the prediction of the Roy equations for different value of a_0 in the range [0.22,0.26].

the four form factors can be further expanded in powers of $q^2 = (M^2_{\pi\pi}/4m^2_\pi) - 1$:

$$F_s = (f_s + f_s^{'} q^2 + f_s^{''} q^4), \quad F_p = f_p, \quad G_p = (g_p + g_p^{'} q^2), \quad H_p = h_p$$

and only the phase shift $\delta(q^2) = \delta_s - \delta_p$ is taken into account. About 677500 decays were selected looking for events in which three good reconstructed tracks are identified in the magnetic spectrometer. The particle identification, to distinguish between electron and pions, exploits the ratio between the energy measured in the calorimeter and the momentum in spectrometer (that is 1 for electrons). The background, coming mainly from $K^\pm \to \pi^\pm\pi^+\pi^-$ decay with a pion misidentified as electron or with a pion decay $\pi \to e\nu$, is evaluated by studying the "wrong" sign events, i.e. the events for which the $\Delta S = \Delta Q$ rule is violated (we are not sensitive to measure this violation). The total background is at level of 0.5%. In order to fit the form factors and the phase shift, the whole data sample has been subdivided in 15000 bins defined in the Cabibbo-Maksymowicz variables 5 dimensional space, and a GEANT3 [5] based montecarlo has been employed. In particular in each of the 10 bins along $M_{\pi\pi}$ a 4 parameters fit was performed in order to extract the form factors. A second fit is made to determine the form factors q^2 dependence. In the case of the phase shift δ, the Roy equations [6] are used to fit the q^2 dependence. Through the Roy equations, after an extrapolation from $\pi\pi$ scattering data at higher energy, it is possible to correlate the δ phase shift to the scattering lengths a_0 and a_2. In tab. 1 the form factors results are summarized, while in fig.2 the phase shift dependence on $M_{\pi\pi}$ is shown as fitted with the Roy equations.

3. Cusp in $K^\pm \to \pi^\pm\pi^0\pi^0$

The pion scattering lengths can also be measured through the study of the "cusp" in the $\pi^0\pi^0$ invariant mass distribution (M^2_{00}) in $K^\pm \to \pi^\pm\pi^0\pi^0$ decay. As shown in fig.3, at $2m_\pi$ a

Table 1. Preliminary results with statistical and systematics error

$f_s^{'}/f_s =$	$0.0165 \pm 0.009 \pm 0.006$	$g_p/f_s =$	$0.0873 \pm 0.013 \pm 0.013$
$f_s^{''}/f_s =$	$-0.090 \pm 0.009 \pm 0.007$	$g_p^{'}/f_s =$	$0.081 \pm 0.022 \pm 0.014$
$f_e^{'}/f_s =$	$0.081 \pm 0.008 \pm 0.008$	$h_p/f_s =$	$-0.411 \pm 0.019 \pm 0.007$
$f_p/f_s =$	$-0.048 \pm 0.004 \pm 0.004$		
$a_0 m_\pi =$	$0.233 \pm 0.016 \pm 0.007$	$a_2 m_\pi =$	$-0.047 \pm 0.011 \pm 0.004$

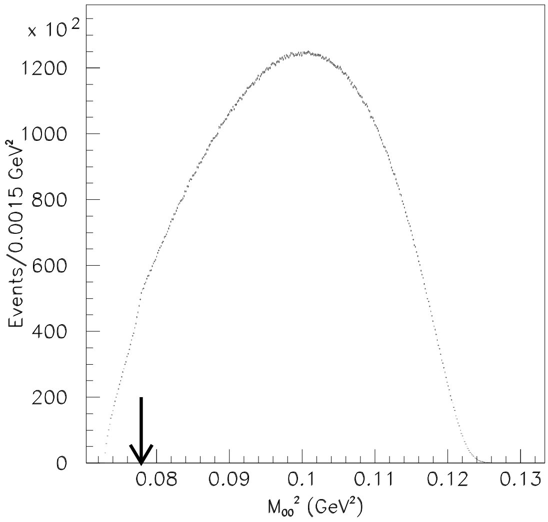

Figure 3. $M^2_{\pi^0\pi^0}$ mass distribution in $K^\pm \to \pi^\pm\pi^0\pi^0$. The arrow indicates the position of $2m_{\pi\pi}$.

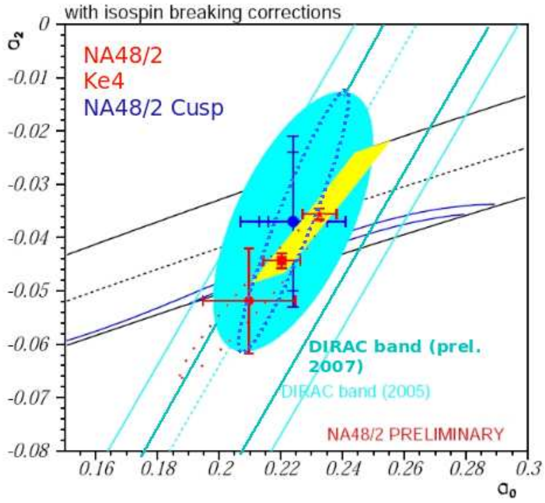

Figure 4. Comparison of the NA48/2 results in the a_0 and a_2 plane.

singularity (cusp) appears; this cannot be explained by the simple parametrization of the matrix element [7]. The interpretation of this structure was given by [8] as due to the $\pi^+\pi^- \to \pi^0\pi^0$ strong rescattering, having different real and imaginary behaviour below and above the $2\pi^+$ production threshold. The fit of the M^2_{00} shape distribution, taking into account the detector acceptance and including the description of one and two loops (as described in [9]) strong rescattering processes, allows to extract $a_0 - a_2$ and a_2. The selection of $59.6 \cdot 10^6$ $K^\pm \to \pi^\pm\pi^0\pi^0$ ($\sim 85\%$ of the whole statistics) is based on the LKr. Four good gamma events are selected and the kaon mass is obtained adding the information from the spectrometer on the charged pion. Thanks to the sizeable statistics collected and the good resolution on the π^0 mass given by the LKr, the cusp structure is very evident. The fit is performed excluding a small region around the threshold where the theoretical treatment of the electromagnetic interaction is still missing. The preliminary results obtained are[1]:

$$(a_0 - a_2)m_\pi = 0.261 \pm 0.006_{stat} \pm 0.003_{syst} \pm 0.0013_{ext}$$

$$a_2 m_\pi = -0.037 \pm 0.013_{stat} \pm 0.009_{syst} \pm 0.0018_{ext}$$

in agreement with our previous result based on a partial set of data [10].

4. Conclusions

Two different way to measure the $\pi\pi$ scattering lengths are exploited by NA48/2 in kaon decays. The first is based on the measurements of the phase shift and the form factors in K_{e4} decay, the second on the accurate study of the Dalitz Plot distribution in $K^\pm \to \pi^\pm\pi^0\pi^0$ decay. In fig.4 the agreement between the two independent measurement is shown together with other experimental results[2].

[1] The external error is assigned taking into account the missing higher order and Coulomb corrections

[2] In red the points obtained with the K_{e4} method (with different assumption in the fit and for the a_0 and a_2 correlation), in blu the central point of the cusp analysis. The light blue ellipse shows the present situation due to the total error on the cusp measurement, the dotted blue ellipse shows the error excluding the external error component.

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