# Precision Measurement of Charged Kaon Decay Parameters (*Experiment NA48/2 at CERN SPS*)

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A high statistics study of charged kaon decays is proposed using a novel design for simultaneous $K^+/K^-$ beams, and NA48 setup. The main goal is to measure CP-violating asymmetry in $K^\pm \to \pi^+\pi^-\pi^\pm$ decays with an accuracy of $\sim 10^{-4}$. In addition more than $10^6$ of $K_{e4}$ decays will be reconstructed to measure a $\pi - \pi$ scattering length parameter $a_0^0$ with an accuracy of better than 0.01. Other charged kaon rare decays will be studied as well.

## 1 Direct CP-violation

New measurements of the direct CP-violation in two–pion decays of neutral kaons very recently done by NA48 [1],[2] and KTEV [3] have confirmed the relatively high value of $Re(\epsilon'/\epsilon)$ first measured by NA31 at CERN [4] more than 10 years ago. That is higher than the predictions of most theoretical evaluations and could indicate to problems in the non perturbative calculations of decay matrix element, or even to disagreement with the Standard Model (SM) [5]. Thus a measurement of direct CP-violation in other processes, like charged kaon decays, is of great interest.

A manifestation of direct CP-violation would be any difference between the $K^+$ and $K^-$ decay matrix elements. The decays which could be compared are $K^+ \to \pi^+\pi^-\pi^+$ relative to $K^- \to \pi^+\pi^-\pi^-$, and $K^+ \to \pi^0\pi^0\pi^+$ relative to $K^- \to \pi^0\pi^0\pi^-$. The matrix element for the decays $K^\pm \to 3(\pi)^\pm$ can be conveniently parametrized in following form [6]:

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

where $u = (s_3 - s_0)/m_\pi^2$, $v = (s_1 - s_2)/m_\pi^2$, $s_0 = \frac{1}{3}(s_1 + s_2 + s_3)$, $s_i = (P_K - P_i)^2$, $P_K$ and $P_i$ are the four-momenta of the kaon and pion ($i = 3$ for the odd pion), respectively, and $m_\pi$ is the mass of the charged pion. The coefficients $g$, $h$ and $k$ must be the same for the decays $K^+ \to 3(\pi)^+$ and $K^- \to 3(\pi)^-$ in case of CP conservation. As a measure of direct CP violation the asymmetry

$$A_g = (g^+ - g^-)/(g^+ + g^-)$$

is considered, where $g^+$ and $g^-$ are the above defined coefficients for the $K^+$ and $K^-$ decays, respectively.

Theoretical predictions for $A_g$ based on the SM lay within the range of values from $\sim 2\times10^{-6}$[7] to $\sim 2 \times 10^{-5}$[8], or even to $\sim 3 \times 10^{-4}$[9]. However it could be calculated as $(2 - 4) \times 10^{-4}$ based on the model with extended number of Higgs dublets [10], or $\sim 10^{-4}$ in the framework of SUSY models [11].

The only direct measurement of $A_g = (-7 \pm 5) \times 10^{-3}$ [12] is based on $\sim 3 \times 10^6$ events. The HyperCP experiment at FNAL has collected $\sim 4 \times 10^8$ decays of $K^\pm$ and statistical precision is expected to be $\sim 6 \times 10^{-4}$ [13]. The relevant measurements with precision of $\sim 10^{-4}$ are planned in the experiments KLOE [14] at DAPhNE (Frascati) and OKA [15] at U70 (Serpukhov).

It is proposed in the experiment NA48/2 to measure any variation in the ratio:

$$R(u) \equiv \frac{\int dv|M^+(u,v)|^2}{\int dv|M^-(u,v)|^2}, \quad (1)$$

where $M^+$ and $M^-$ are the matrix elements for $K^+$ and $K^-$ respectively, as a function of the variable $u$, which would manifest evidence of direct CP violation.

To measure the $R(u)$ with minimum systematic uncertainty it is foreseen to take data under the following conditions:

- $K^+$ and $K^-$ beams derived from the same target and are present simultaneously, such that the decays of $K^+$ and $K^-$ occur in the same fiducial volume;
- the field of the spectrometer magnet is frequently alternated in sign, so as to equalize the acceptances for $K^+$ and $K^-$ decays even in the presence of localized imperfection in the detector;
- the data are binned in kaon momentum and the ratios (1) measured for the spectrometer magnetic field orientation UP and DOWN are averaged for each kaon momentum bin. The final value obtained by averaging these ratios over all momentum bins is independent of acceptance.

The beam of charged particles are derived from primary protons from the SPS transported at zero angle onto the present target station T10 consisting of 2 mm diameter, 400 mm long beryllium target followed by a water cooled copper collimator. The central momentum and momentum bite are selected as $60 \pm 3 GeV/c$ symmetrically for positively and negatively charged particles by their passage through the first "beam achromat" represented by two vertical deflection dipole magnets with opposite sign field and a pair of dump/collimators having similar openings for each of the two beams, and two further vertical deflection magnets to return the two beams onto a common axis). This achromat is followed by a defining collimator. The layout of the complete beam line is shown schematically in Fig. 1. The two beams with an angular acceptance from the target of $\pm 0.36$ mrad, are focused to be parallel, by a set of quadrupole quadruplet system located after the defining collimator. The second achromat is placed just after the focusing system and includes two stations of Micromegas type position sensitive detector. They are located after the second dipole in the positions of positive and negative beams respectively. The third such station is installed after the second achromat in the common beam line. All three stations define a beam spectrometer measuring the momentum of individual charged particle with a precision of $\sim 1\%$. A final collimator installed at 102 m from the target, is followed by a decay volume of $\sim 100$ m length.

The rates for the proposed simultaneous $K^+$ and $K^-$ beams estimated for $10^{12}$ protons of 400 GeV/c per pulse incident on the target, at long duty-cycle SPS cycle, are listed in Table 1. The decays of kaons are estimated for one year of running taking into account 120 day run with an efficiency of 50%.

Table 1. *Particle fluxes in the beams*

| | $K^+$ beam | $K^-$ beam |
|---|---|---|
| p / cycle, in $10^6$ | 8.6 | 0.9 |
| $\pi$ / cycle, in $10^6$ | 33.2 | 24.6 |
| K / cycle, in $10^6$ | 3.1 | 1.8 |
| $K3\pi$ decays / year, in $10^{10}$ | 1.4 | 0.8 |

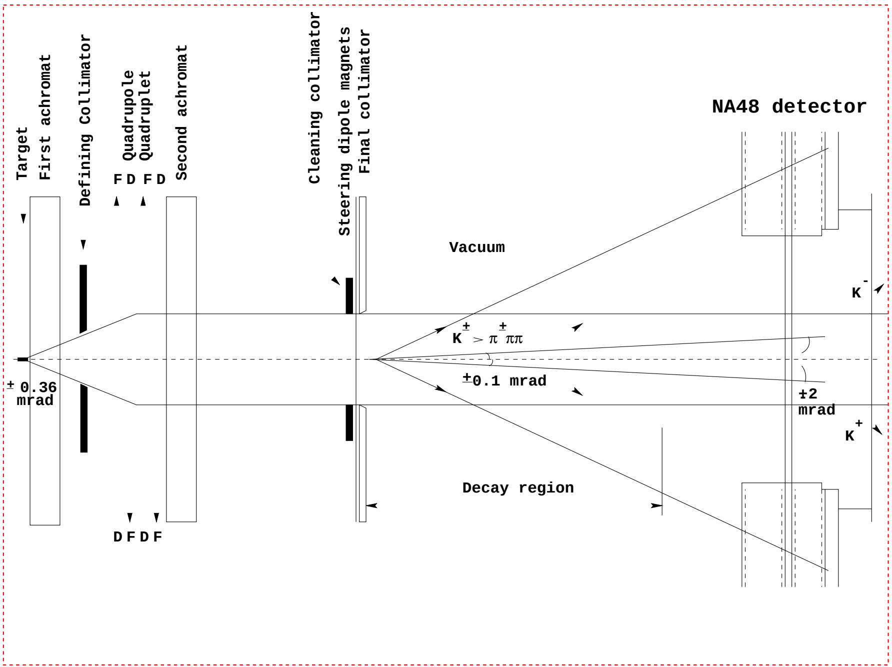


Fig. 1. *The complete layout of the simultaneous $K^+$ and $K^-$ beams.*

The major elements of the existing detector are the magnetic spectrometer with regularly alternated polarity of the field, liquid krypton electro-magnetic calorimeter, hadron calorimeter, muon veto and hodoscope of scintillator counters, which could be used in the proposed experiment without any modifications. The only additional detector is the transition radiation detector (TRD), which is needed to separate electrons/positron from the hadrons for the reliable identification of some rare decays, like $K^c_{e4}$.

The trigger requirements are based on signals that are already available in the NA48 experiment. A coincidence of hits in the opposite quadrants of the hodoscope will be required as a pre-trigger condition. Level 2 trigger will be modified to select events with 3 or 2 charged tracks to reconstruct 1 or 2 vertex(s), respectively, in the fiducial region coincident in space within the expected resolution.

Two types of events of $K^\pm \to 3(\pi)^\pm$ decay, with two or three pions accepted by the detector, could be reconstructed. The Monte Carlo simulation has shown that both of them are useful for the asymmetry measurement. The acceptance for these events is around 70%. Taking into account the kaon fluxes (Table 1) $1.17 \times 10^{10}$ of $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ decays and $0.24 \times 10^9$ of $K^\pm \to \pi^\pm\pi^0\pi^0$ decays could be accumulated in one year of typical SPS running, which leads to the statistical precision of $0.7 \times 10^{-4}$ and $2.2 \times 10^{-4}$ for the measurements of $A_g$ and $A^0_g$, respectively.

Estimation of systematic uncertainties of $A_g$ caused by possible difference in the $K^+$ and $K^-$ beam momentum measurements and the angular difference of their beam axes, accidentals in the detector, pions punch through effects, and others, indicates that it could be controlled at the level of $5 \times 10^{-5}$.

## 2 $K^c_{e4}$ and other decays

In addition, a study of $K^c_{e4}$ decays could be performed, which allows to prove the existence of the postulated $q\bar{q}$ condensate of the QCD vacuum, and to measure accurately chiral perturbation theory (ChPT) parameters. A measured parameter $a^0_0$ - an S-wave pion-pion scattering length, could indicate to large (=0.20) or vanishing (=0.30) condensate respectively [16]. The study performed by Geneva-Saclay experiment [17], which is based on 30000 $K^c_{e4}$ events with 1% of background, has obtained $a^0_0 = 0.263 \pm 0.052$. The resent experiment at Brookhaven accumulated $\sim 437000$ events with 2% background. The preliminary result is $a^0_0 = 0.229 \pm 0.013$ [18].

In the NA48/2 experiment it is expected to accumulate more than $10^6$ $K^c_{e4}$ decays with the background less than 1% in one year of running. That allows to measure $a^0_0$ with an accuracy of 0.01 and establish the size of the QCD condensate.

Significant statistics of rare decays: $K^\pm \to \pi^\pm 2\gamma$ ($10^3 - 10^4$ events), $K^\pm \to \pi^\pm\pi^0\gamma$ ($\sim 10^5$ events), $K^\pm \to \pi^\pm l^+ l^-$ ($\sim 10^8$ events), and others, could be accumulated as well.

## Conclusion

The proposed experiment NA48/2 with the unique simultaneous $K^+/K^-$ beams and an extended apparatus of existing NA48 detector could provide precision measurements of CP-violating asymmetry $A_g$ at the level of $\sim 10^{-4}$ and $\pi - \pi$ scattering length parameter $a^0_0$ with a precision of $\pm 0.01$, and obtain new information on some other rare decays.

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