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Recent results on Direct CP Violation and charged kaon decays with the NA48/2 experiment

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The CP violation played an important role in the understanding of the intimate nature of the weak interaction from the early times of particle physics. After more than three decades since the discover of CP violation in the neutral kaons by Christenson, Cronin, Fitch and Turlay [1] a new kind of CP violation, the so called *Direct CP violation* that happens directly in the decay, was definitively discovered. After the unconfirmed indication by NA31 [2], KTev [3] and NA48 [4] have demonstrated, with high significance, that direct CP violation exists in the decays of neutral kaons into two pions (only recently the direct CP violation has been found also in the B sector [5]).
However the deep understanding of the CP violation is still an important tool both in the test of Standard Model (SM) and in the discovery of the physics beyond the SM. Indeed a possible non-SM structure could appear in the heavy quarks loops which are responsible of the direct CP violating processes. Besides the already measured quantity ε'/ε, the most promising observables are the charge asymmetry in the $K \rightarrow 3\pi$ decay and the decay rates of the GIM suppressed decays. The main goal of the NA48/2 experiment is to measure the charge asymmetry in the 3π mode of the charged kaons with a statistical precision of $\sim 10^{-4}$ and a smaller systematic error, both in $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ and in $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$. A novel design for the beam line and an upgrade of the NA48 detector are adopted to allow the simultaneous detection of decays from K+/K- unseparated beams. After a brief description of the beam line and detector, the analysis technique and the main systematics will be discussed to present the preliminary result in the charged mode:

$$\begin{aligned} A_g^c &= (0.5 \pm 2.4_{stat} \pm 2.1_{stat(trig)} \pm 2.1_{syst}) \cdot 10^{-4} \\ &= (0.5 \pm 3.8) \cdot 10^{-4} \quad . \end{aligned}$$

The analysis in the neutral mode will be briefly discussed.

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The easiest way to look for any difference in the charged conjugates Kaon decays is to compare the *Dalitz Plot* shape. This can be formalized expanding the matrix element as:

$$|M|^2 \propto 1 + gu + hu^2 + kv^2 + ... \quad ,$$

where the coefficient g is called *linear slope*[1] and where the *Dalitz variables* u and v are defined as [2]:

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

NA48/2 wants to measure the linear slope asymmetry:

$$A_g = \frac{g_+ - g_-}{g_+ + g_-} \quad ,$$

with a precision of $2.2 \cdot 10^{-4}$ for the $\pi^\pm\pi^+\pi^-$ (A_g^c,"charged") decay mode and $3.5 \cdot 10^{-4}$ for the $\pi^\pm\pi^0\pi^0$ (A_g^n,"neutral") decay mode, increasing by a factor 10 the present experimental sensitivity. The best present measurement are [6] A_g^c=$(22 \pm 15 \pm 37) \cdot 10^{-4}$ (prelim.) and [7] A_g^n=$(2 \pm 19) \cdot 10^{-4}$ based on $54 \cdot 10^6$ and $620 \cdot 10^3$ events respectively. The theoretical prevision for this quantity depends from the calculation of the strong loops giving results from 10^{-6} to 10^{-5} but all the authors agree that a value of A_g greater then $5 \cdot 10^{-5}$ could be signal of new physics.

In order to match this goal NA48/2 took data in two periods (50 days in 2003 and 60 days in 2004) using two high intensity, simultaneous and focused K+/K- beams, collecting 4 billions of $K^\pm \to \pi^\pm\pi^+\pi^-$ and 100 millions of $K^\pm \to \pi^\pm\pi^0\pi^0$.

1. The NA48/2 experiment

The NA48/2 detector is based essentially on the existing NA48 setup and infrastructure, with a novel beam line design to transport simultaneously K+ and K- beams that overlap in the decay region. The hadron beams are produced using primary 400 GeV protons from the SPS @CERN impinging a beryllium target. The particles of opposite charge are split, selected in a narrow momentum band ($p_k = 60 \pm 3GeV$) and then recombined by passing trough an achromatic device.

The central NA48 detector is described elsewhere [8]. The spectrometer magnet was operated in order to give $Pt_{kick} = 120MeV/c$ and the resolution in momentum (GeV/c) is $\sigma_p/p = 1.0\% \oplus 0.044$. To detect the photons, for the neutral mode, the LKr calorimeter provides a very good energy (GeV) resolution of $\sigma_E/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$. Thanks to this performance the resolution on the recostructed kaon mass is good enough (1.7 MeV in the charge mode, 1.2 MeV in the neutral mode) allowing for precise calibration and monitoring of the detector instabilities itself. A two level trigger is employed to reduce the rate of data collection. An hardware level trigger (L1) using fast information from a hodoscope counter is followed by a L2 selection based on the number of online reconstructed tracks (for the charge mode) and the kinematic rejection[3] of the $\pi^+\pi^0$ for the events with one track only. The final trigger rate is 10KHz.

[1] the *quadratic slopes* h and k are small with respect to g.

[2] where $s_i = (p_K - p_i)^2$ with index 3 for the odd pion, and $s_0 = (s_1 + s_2 + s_3)/3$.

[3] In the one track event the missing mass (assuming the kaon direction of flight) is required to be different from the π^0 .

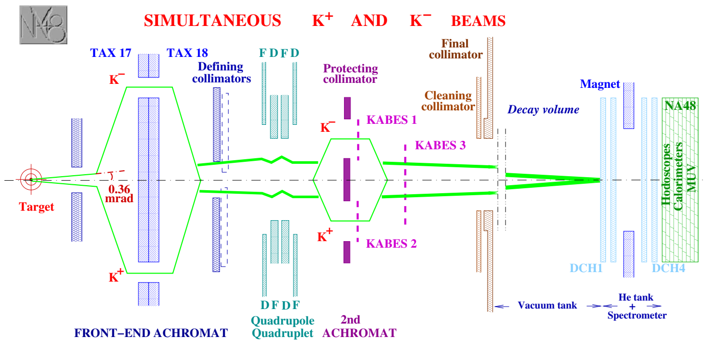

Figure 1: The NA48/2 beam line and detector. Not in scale.

2. Asymmetry analysis: the charged mode

The method to extract A_g is based on the comparison between the U distribution of the K^+ and K^- decays. In case of $\pi^\pm\pi^+\pi^-$ decay the value [9] of $g = (-0.2154 \pm 0.0035)$ authorizes some approximations to obtain:

$$R(u) = \frac{N_{K^+}}{N_{K^-}} \propto (1 + \Delta g \cdot u) \quad ,$$

where $\Delta g = g_+ - g_-$. A linear fit is used to extract Δg connected to A_g by the relation $A_g = \Delta g / 2g$.

However the presence of magnets both in the beam sector (achromats, focusing magnets, etc.) and in the detector (magnetic spectrometer) introduces a intrinsic charge asymmetry of the apparatus. In order to equalize this asymmetry the main magnetic fields are frequently reversed during the data taking (the beams magnets are inverted on a weekly basis, the spectrometer magnet on a daily basis). For each achromat polarity it's possible to define ratios in which the same part of the spectrometer is involved for opposite charge of the kaons. In particular the product of the two ratios[4]:

$$R_J(u) = \frac{N^{B^-}_{K^+}}{N^{B^+}_{K^-}} \,, \qquad R_S(u) = \frac{N^{B^+}_{K^+}}{N^{B^-}_{K^-}} \quad ,$$

assures that the acceptance differences, due to the spectrometer magnet, are cancelled automatically. The full cancellation of all the acceptance asymmetries is obtained in the *quadruple ratio*[5]:

$$R(u) = R_{US} R_{UJ} R_{DS} R_{DJ} \sim \bar{R}(1 + 4\Delta g u) \quad .$$

The presence of stray magnetic fields (earth field, etc.) is taking into account by measuring directly and applying corrections in the reconstruction. Due to the fact that the quantities in the numerator and in the denominator of each ratios are collected in different periods, this method is sensitive only from the time instabilities of the detector which have a characteristic time smaller than the corresponding field alternation period. Due to the superposition of the two beams and the cancellation of the acceptance asymmetries, the measurement does not need a Monte Carlo.

[4]The letters J (Jura) and S (Saleve) represent the two mountain on the left and right with respect to the kaons directions.

[5]The letters U (Up) and D (Down) represent the path (upper or lower) in which the K^+ runs in the achromat .

Acceptance and beam geometry	0.5
Spectrometer alignment	0.1
Analysing magnet	0.1
Pion decay	0.4
Calculation of u and fitting	0.5
Pile-up	0.3
Trigger	0.9

Table 1: Limits on systematics uncertainties on Δg in units of 10^{-4}.The valuation of the systematic is conservative at this level and the trigger component of the uncertainty could be reduced.

The only detectors involved in the "charged" analysis are the spectrometer and the hodoscope for trigger purpose. The event selection is quite simple due to the fact that the channel $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$, with a $BR = (5.576 \pm 0.031)\%$ [9], is essentially background free. Three tracks are required asking for quality cuts on the reconstruction in symmetric way for K^{+} and K^{-}. The good resolution on the kaon mass ($\sim 1.7 MeV$) allows to cut $9 MeV/c^2$ around the nominal mass to decrease the contribution of the secondary pion decay. As mentioned above particular care is necessary to check the stability in time of the detector and beams. The beam movements can introduce difference in the acceptance cuts, mainly due to the inner cut (due to the physical presence of the beam pipe) in the chambers. To avoid this, the position of the center for both beams is recorded by measuring the center of gravity in every run and a cut around the actual center is performed separately for K^{+} and K^{-}. The movement of the beam during the spill (observed directly using a beam monitor in the last part of the beam pipe) does not introduce additional corrections. Also the dependence of the beam position from the kaon momentum is taken into account. A conservative limit on residual systematic uncertainty, $\delta(\Delta g) = 0.5 \cdot 10^{-4}$ was determined studying the sensitivity of the result to various acceptance cuts. The variations of the characteristics of the spectrometer are observed by looking for the difference between K^{+} and K^{-} masses in the same run [6]. An other important source of systematic errors is the trigger. The level 1 trigger is very efficient ($> 99\%$) and no correction is applied on the data. A small correction is applied for the L2, by measuring the trigger efficiency variation with time ($> 98\%$) as a function of u. However the systematic bias due to the trigger is fully dominated by the statistics in the control samples. Tab.1 summarizes the mains systematic uncertainties attributed for this preliminary result.

The preliminary result presented in this paper on the "charged" mode is based on the whole sample collect in 2003 , which includes $1.6 \cdot 10^{9}$ $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$. The stability of the result was checked with respect to several variables (kaon energy, vertex position, etc.) without finding any significant dependence. The preliminary result is

$$\begin{aligned} A_g^c &= (0.5 \pm 2.4_{stat} \pm 2.1_{stat(trig)} \pm 2.1_{syst}) \cdot 10^{-4} \\ &= (0.5 \pm 3.8) \cdot 10^{-4} \quad . \end{aligned}$$

[6] A residual horizontal shift can introduce this splitting in the measured masses and a charge asymmetric mismeasurement of the momenta. Also a non perfect inversion of the spectrometer magnet can introduce a variation in the measured kaon mass (coherent between opposite charge in the same run). These two effects are corrected forcing the kaon masses to be equal for opposite charge and also equal to the nominal PDG value.

This result is consistent with no CP violation with a precision one order of magnitude better than earlier experiments. The 2004 data sample, which is being analyzed, contains more data than in 2003 and the systematic error could be lower thanks to the more frequent change of the magnets polarities.

3. Asymmetry analysis: the neutral mode

NA48/2 collected the largest samples of $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$. The analysis of the asymmetry is quite advanced and the final result could be competitive with the charged mode. In spite of the lower statistics ($\sim 60 \cdot 10^{6}$ events in 2003) the most favourable Dalitz Plot distribution and the greater value of $g = 0.638 \pm 0.020$ give a smaller statistical error on $\delta(A_g^n) = 1.7 \cdot 10^{-4}$. The analysis technique is very similar to that described above. The systematics biases are completely different with respect to the charged mode, due to the fact that the detector involved in the studies of this decay is, mainly, the LKr calorimeter. Thanks to the fact that gammas are neutral the A_g^n is less sensitive to the kaon polarity with respect the three charged pions mode. The small acceptance difference between the two beams is cancelled out in the quadruple ratio. The main systematics uncertainties come from the trigger and the accidental activity. Anyway the total systematics error is at level of the statistical one. The U distribution can be constructed in two complementary ways, using the LKr alone or using KABES and the spectrometer. The two results can cross check each other.

At the beginning of November 2005[7] the NA48/2 collaboration presented the preliminary result[10]:

$$
\begin{aligned}
A_g^n &= (1.7 \pm 1.7_{stat} \pm 1.2_{stat(trig)} \pm 1.3_{syst} \pm 0.2_{ext}) \cdot 10^{-4} \\
&= (1.7 \pm 2.4) \cdot 10^{-4} \quad .
\end{aligned}
$$

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