Preliminary results on CP violation in charged K decays at NA48/2

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The NA48 collaboration is studying the decays of charged kaons, with the main aim of searching for direct CP violation in the decay of the charged kaon into three pions. The collected data represents the largest charged kaon decay sample in the world. The expected statistical error is $\approx 2 \cdot 10^{-4}$.

1. Physics motivations

The NA48 collaboration, after the measurement of the direct CP violation in the decay of neutral kaons[1][2][3] and a study of rare K_S decays with an high intensity beam[4][5][6], has started [7] in 2003 the study of charged kaon decays using simultaneous charged beams.

The main interest is to search for direct CP violation in the decays of charged K into three pions.

Direct CP violation manifests itself in a value different from zero of the asymmetry

$$A_g = \frac{g^+ - g^-}{g^+ + g^-}$$

where $g^{\pm}$ is the Dalitz plot slope for the decays of $K^{\pm}$ and the matrix element of the decay is parametrized as

$$\mid M(u,v) \mid^2 \propto 1 + g \cdot u + h \cdot u^2 + k \cdot v^2,$$

u and v being the usual Dalitz plot variables.

Theoretical predictions [8] [9] [10] [11] [12] give values for A_g between 10^{-4} and 10^{-6}. In a recent paper [13], the value 10^{-5} is considered coherent with the Standard Model, while a result bigger than $5 \cdot 10^{-5}$ will be a sign of new physics. The only existing measurement [14] gave $A_g = (-7 \pm 5) \cdot 10^{-3}$ with $1.6 \cdot 10^6$ decays. NA48 can accumulate at least $2 \cdot 10^9$ decays and reach a statistical error of $\approx 10^{-4}$. In the channel $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ it is expected to have more than 100 million events for a statistical error of $\approx 2.5 \cdot 10^{-4}$.

Another possible study is that of the K_{e4} decay, which allows the measurement of the $\pi\pi$ scattering length parameter a_0^0 with an accuracy of better than 0.01. The best measurement up to now is [15] $a_0^0 = 0.228 \pm 0.012_{st} \pm 0.003_{sy}$.

High statistics in $K^{\pm}$ decays allows also the study of several rare decays ($K^{\pm} \to \pi^{\pm}\gamma\gamma$, $K^{\pm} \to \pi^{\pm}e^+e^-$, $K^{\pm} \to \pi^{\pm}\pi^0\gamma$) to test χPT predictions at next-to-leading order. In addition a measurement of $\mid V_{us} \mid$ can be extracted from the study of K_{e3} and $K_{\mu 3}$ decays.

2. The beam and the detector

The NA48 detector [1] has been used in combination with a new beam setup (fig. 1) which allows to have simultaneous K^+ and K^- in the decay region.

A 400 Gev/c proton beam with an intensity of $7 \cdot 10^{11}$ protons/pulse produces on a secondary target positive and negative charged kaons at zero degree. 2 achromat systems, each one consisting of 4 magnets with deflection in the vertical plane and of suitable collimators, select the momentum of the two beams to be 60 Gev/c with a spread of 3.8%. The two beams are then brought to the detector axis and focused at the spectrometer position.

In the second achromat and downstream of it, there are two micromegas detector (Kabes) to measure the vertical coordinates of the beams, allowing the determination for each kaon decay of the sign and the momentum of the parent particle.

These detectors make possible the resolution of the two-fold ambiguity in the reconstruction of the K_{e4} decay kinematics and also the possibility

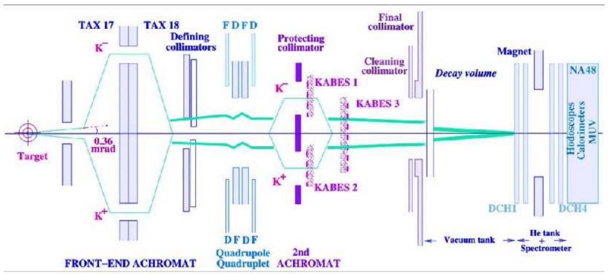

Figure 1. *The simultaneous charged kaon beams*

to fully reconstruct events from K$^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ where one of the pions escapes detection. An additional help is provided in the study of many rare decay channels.

Typical resolutions of the Kabes detectors are 650 psec in time and 0.8% in the K momentum.

3. Statistics

During the last month of the data taking in 2003, when the running conditions were stable, about 1.1 billion K$^{\pm} \rightarrow \pi^{\pm}\pi^{-}\pi^{+}$ decays were collected. An additional statistics of 30 million K$^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ has been collected and an analysis of the asymmetry in this channel is also going on.

4. Analysis

The quantity measured experimentally is

$$R(u) = \frac{\int dv|M^{+}(u,v)|^2}{\int dv|M^{-}(u,v)|^2} \approx 1 + u \cdot (g^{+} - g^{-})$$

which relies on acceptance cancellation between K^{+} and K^{-}. To minimize systematics, the data are taken under the following conditions:

- Simultaneous decays of K^{+} and K^{-} in the fiducial volume

- Alternance of the sign of the spectrometer field to equalize acceptances in the presence of localized imperfections in the detector

- Alternance of the acromat sign settings to symmetrize the paths followed by the charged particles

This automatic compensation doesn't work if an undetected asymmetric change in the acceptance occurs during or between runs. An independent and careful monitor of the detector during the run is crucial to spot any possible change which could affect the symmetry of data taking. Moreover, several precautions have been taken to be sure 'a priori' of the symmetrization of the detector, like cabling the readout of the drift chambers in such a way that a failure of one board is reflected in symmetric sectors of the chamber.

4.1. Time instabilities

The two specific time instabilities which mostly affect the data and may contribute to a fake asymmetry are the time dependence of the spectrometer response and the time dependence of the beam geometry. Both effects has been thoroughly studied to correct the data.

4.1.1. Spectrometer response

All the momenta of the pions have been corrected with the following formula

$$P = P_0 \cdot (1 + \beta) \cdot (1 + qb\alpha P_0)$$

where P_0 is the measured momentum, P the corrected momentum, q the charge of the pion and b the sign of the magnetic field.

α is a time dependent parameter related to the drift chamber misalignment (computed imposing M$_{K^+}$=M$_{K^-}$). The alignment of the spectrometer has been found to move in 2003 of a quantity equivalent to the displacement of 70 μm of the last chamber (i.e. a difference of 120 Kev/c^2 between M$_{K^+}$ and M$_{K^-}$).

β is related to the B field integral which can be different when changing its sign. β is computed imposing that the reconstructed mass of the kaon is equal to the PDG value.

4.1.2. Beam geometry

It has been found that the beam position at the detector (i.e. the center of gravity of the transverse coordinates of the three pions) moves during the burst of about 1-2 mm, in a different way for

K$^+$ and K$^-$. Moreover, the COG position is also dependent from the kaon momentum and sign. The detector acceptance is defined by the beam pipe, so any movement wrt the center of the pipe, if not symmetric, can induce an asymmetry in the result. For that reason one uses a radial cut which is a function of kaon momentum, sign and time.

4.2. Asymmetries

The analysis uses the slopes of ratios of event distributions for positive and negative kaons with different spectrometer field signs. Several different ratios can be built to extract the physics information or to control the systematics of the detector.

Indeed, the slopes A_S and A_J of $\frac{N_{B+K+}}{N_{B-K-}}$ and of $\frac{N_{B+K-}}{N_{B-K+}}$ are not affected from a left-right detector asymmetry stable in time, while symmetric changes will affect both, but not their average. This average, if different from zero, is a sign of CP violation.

The slopes A_+ and A_- of $\frac{N_{B+K+}}{N_{B-K+}}$ and of $\frac{N_{B+K-}}{N_{B-K-}}$ are affected by symmetric changes even in their average, while left-right asymmetric changes compensate in the average. These slopes contain information on the systematics of the detector, as they don't contain CP violation physics (the ratios are taken with kaons of the same sign).

Fig. 2 shows the dependence of A_S, A_J and their averages as a function of the data taking time. The values for the slopes are shown with an offset. In the A_S, A_J plots, where CP violation could reveal itself, the statistical error is $\approx 2 \cdot 10^{-4}$.

The plots for A_+, A_- and their average (Fig. 3), sensitive to residual systematics, are compatible with no effects within the statistical error cited above.

4.3. Study of K_{e4} decays

It is expected to have a final sample of at least $7 \cdot 10^5$ K_{e4} decays in the data collected in 2003. A preliminary analysis has been performed on a subsample of about 16K events: a branching ratio of $(3.87 \pm 0.20) \cdot 10^{-5}$ has been measured, in agreement with the PDG value of $(4.08 \pm 0.09) \cdot 10^{-5}$. The study of the background (i.e. 3 pion decays with one pion identified as an electron or as a

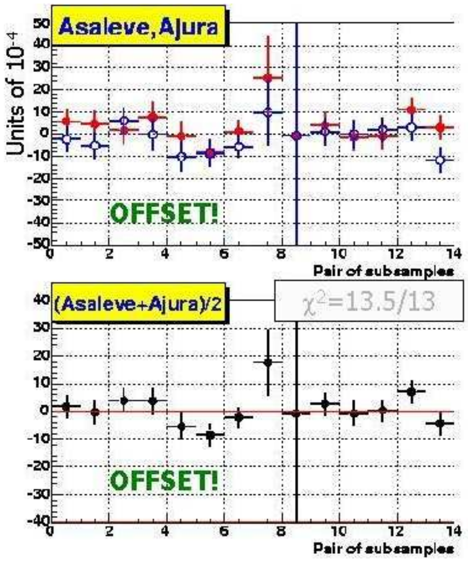

Figure 2. *Slopes A_s, A_j and their average as a function of data taking period*

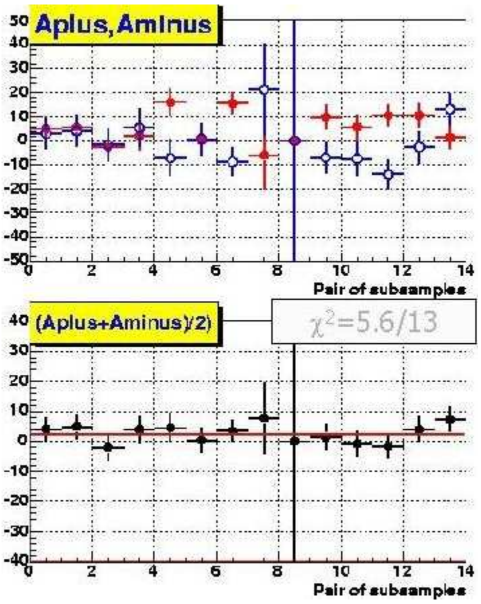

Figure 3. *Slopes A_+, A_- and their average as a function of data taking period*

$K^{\pm} \to \pi^{\pm}\pi^{0}$ decay with a Dalitz pair) shows that it can be controlled below 1%. This is achieved also thanks to a neural network method to improve e/π rejection.

4.4. Study of rare $K^{\pm}$ decays

Several analyses are under way to study rare decays: for example, more than 3500 $K^{\pm} \to \pi^{\pm}e^{+}e^{-}$ decays are available in the 2003 data sample.

For the channel $K^{\pm} \to \pi^{\pm}\gamma\gamma$, despite the lower trigger efficiency, it is expected to have a statistics better than the world sample (31 events).

4.5. Conclusion

The NA48 Collaboration has started the data taking for the study of the decays of charged kaons with the main aim of searching for direct CP violation, collecting in 2003 1.1 billion $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and around 30 million $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays.

In 2004 the data taking has been completed with a preliminary number of $\approx 2 \cdot 10^{9}$ decays in the charged mode and more than 100 million in the neutral mode, giving the largest sample of charged kaon decays in the world.

The analysis for the measure of direct CP violation is under way and the statistical error expected at the end of the experiment for the A_g ratio is $\approx 10^{-4}$ for the decay $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $\approx 2 \cdot 10^{-4}$ for $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$.

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