STATUS AND RESULTS OF THE NA48 EXPERIMENT AT CERN

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The aim of the NA48 experiment at CERN is to measure the direct CP violation parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ in the neutral kaon decays with a precision of 2×10^{-4}. This will be achieved thanks to a significant increase in the data collection and an improved experimental technique, resulting in the reduction of the systematic error. NA48 has successfully concluded the 1997 and the 1998 data taking periods. In this paper the principle of the experiment and the performance of the detector are described. The status of the $\mathrm{Re}(\varepsilon'/\varepsilon)$ analysis on 1997 data is reported. Preliminary results are presented on the analysis of rare kaon decays.

1 The NA48 experimental technique

The NA48 experiment at CERN measures the direct CP violation parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ by comparing the relative decay rates of $\mathrm{K_S}$ and $\mathrm{K_L}$ decaying into pion pair, combined in the *double ratio* R:

$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \cdot \frac{\Gamma(K_S \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^+\pi^-)} \simeq 1 - 6\,\mathrm{Re}(\varepsilon'/\varepsilon)$$

A few million of CP–violating $K_L \to \pi^0\pi^0$ decays, the rarest among the four relevant processes, should be collected to achieve the expected precision of 2×10^{-4} on the $\mathrm{Re}(\varepsilon'/\varepsilon)$ measurement. The detection efficiencies and the rate dependent effects due to accidental activity in the detector cancel, in principle, when calculating R, if the four decays are collected concurrently and in the same fiducial region, defined to be 3 to 4 units of $\mathrm{K_S}$ lifetime.

The $\mathrm{K_S}$ *and* $\mathrm{K_L}$ *beams:* a 450 *GeV* SPS primary proton beam hits a beryllium target at an angle of 2.4 *mrad* and an intensity of 1.5×10^{12} *ppp* (protons per 2.4 *s* SPS pulse), and produces a neutral beam, namely the $\mathrm{K_L}$ one. A fraction of those protons non–interacting in the $\mathrm{K_L}$ target is steered onto a bent silicon crystal [1] and deflected through it. An attenuated proton beam is thus produced, at an intensity of 3×10^7 *ppp*, suitable to generate the $\mathrm{K_S}$ beam. These protons are tagged by a set of thin scintillators [3], installed downstream to the crystal, in order to distinguish $\mathrm{K_S}$ from $\mathrm{K_L}$. They are afterwards transported toward a second beryllium target, 120 *m* downstream to the first one, where the $\mathrm{K_S}$ beam is produced at an angle of 4.2 *mrad*. The two kaon beams [2] converge toward the detector at an angle of 0.6 *mrad*, comparable to the beam divergence, in order to obtain the same detector illumination.

The NA48 detector: the charged decays are analysed by a magnetic spectrometer: four drift chambers [4] are installed in a helium tank at the end of the decay volume, two on each side of a dipole magnet. A scintillator hodoscope performs fast triggering and time measurement for the charged decays.

A liquid krypton (LKr) electromagnetic calorimeter [5] detects the neutral decays. It provides high precision measurements of the photon energy, position, and arrival time, and performs triggering for the neutral decays. A volume of 8 m^3 of LKr, with 27 X_o length, is contained in a cryogenic vessel. Copper–berillium ribbon electrodes define 13212 cells, $2 \times 2\ cm^2$ each, giving a tower read–out structure [6]. The front–end charge preamplifiers and the calibration systems are located at the end plate of the detector, inside the liquid, at 120 K. Fast read–out is achieved by using the initial current read–out technique. The pulses are digitized by a 40 MHz FADC system.

Background effects are critical for the $\mathrm{Re}(\varepsilon'/\varepsilon)$ measurement. Seven double planes of scintillator counters, used as large–angle vetoes, detect photons outside the detector acceptance. The LKr calorimeter is used to reject the background due to the $\mathrm{K_L}$ decays into $3\pi^0$. The muon detector, namely three planes of scintillator counters separated by iron, the lead–scintillator hadron calorimeter and the magnetic spectrometer are used to reject the background due to the charged three–body $\mathrm{K_L}$ decays.

2 The 1997 data taking

The 1997 data taking has been the first physics run of the NA48 experiment. During the 42 days of run, 25 TB of data were recorded, at a beam intensity of $\sim 10^{12}$ ppp, namely $\frac{2}{3}$ of the nominal value. About 650.000 CP–violating $K_L \to \pi^0\pi^0$ decays were collected, the exact number depending on cuts.

Detector performance: the NA48 detector has been performing as expected in 1997. An overall data acquisition system capability of 80 MB/s, over the burst duration, and an event transfer rate to the Central Data Recording of 12 MB/s, through optical link, have been achieved.

A farm of microprocessors [7] calculates the decay vertex position and the kaon invariant mass of the charged candidates, using drift chambers informations. The efficiency of the charged trigger in 1997 was about 90.6% for both $\mathrm{K_L}$ and $\mathrm{K_S}$ decays, due to the misalignement of the signals. The neutral trigger [8] is based on the LKr data. It computes energy sums, number and time consistency of energy clusters, decay vertex positions of the neutral decay candidates. A 99.9% efficiency has been measured for the neutral trigger in 1997, for both $\mathrm{K_L}$ and $\mathrm{K_S}$ events. The final trigger decision was delivered every 25 ns at a 2 kHz rate by a central pipelined device [9].

The drift chambers momentum resolution results in the required resolution on the $\pi^+\pi^-$ invariant mass of about 2.5 MeV/c^2.

Both the read–out of the LKr calorimeter and the neutral trigger electronics were completely installed in 1997. Due to a problem on the HV blocking capacitors, the calorimeter was operating at a reduced electric field value, namely 1.5 KV/cm. This caused a $\sim$ 20% worse signal to noise ratio with respect to the design conditions. A calorimeter column, 4 cm wide, was not connected to the high voltage, causing a loss of $\sim$ 20% in the $K_L \rightarrow \pi^0\pi^0$ acceptance. After the electronic calibration, a resolution of 1.1 MeV/c^2 is measured in 1997 on the π^0 invariant mass, suitable to keep the neutral background at the required level. The energy response is linear within $\sim$ 0.2% in the energy range between 5 and 100 GeV. The energy resolution is:

$$\frac{\sigma(E)}{E} = \frac{3.5\%}{\sqrt{E}} \oplus \frac{110MeV}{E} \oplus 0.6\%$$

3 The $\mathrm{Re}(\varepsilon'/\varepsilon)$ analysis on 1997 data

The $\mathrm{Re}(\varepsilon'/\varepsilon)$ analysis on 1997 data is well advanced. The expected statistical accuracy on the measurement is 4–5 $\times 10^{-4}$. The systematics error is limited by the data statistics available to study each effect. Some selected items of the analysis are described.

The $\mathrm{K_S}$ *tagging technique:* event assignment to $\mathrm{K_L}$ or $\mathrm{K_S}$ is based on the measurement of the time–of–fligh between the time of the protons travelling towards the $\mathrm{K_S}$ target, detected by the tagger scintillators, and the event time. The charged decays event time is provided by the scintillator hodoscope, the time of the neutral decays by the LKr calorimeter. A window of 2 ns for the time–of–flight measurement is used to distinguish between $\mathrm{K_S}$ and $\mathrm{K_L}$. Misidentifications of $\mathrm{K_S}$ into $\mathrm{K_L}$ are mainly due to tagging inefficiency and to errors in the event time measurement. They could generate a fake non–zero value of $\mathrm{Re}(\varepsilon'/\varepsilon)$, charged and neutral decays being reconstructed in different parts of the detector. Transitions of $\mathrm{K_L}$ into $\mathrm{K_S}$ are mostly due to accidental activity of the tagger counters. They do not depend on the decay mode, but only on the rate seen by the tagger. Both those transitions results in a correction to R. The resulting uncertainty on $\mathrm{Re}(\varepsilon'/\varepsilon)$ is $\leq 2 \times 10^{-4}$.

Lifetime weighting procedure: the lifetime weighting is a technique used to reduce the acceptance corrections to $\mathrm{Re}(\varepsilon'/\varepsilon)$. The $\mathrm{K_L}$ decay vertex distribution is made similar to the $\mathrm{K_S}$ one by applying a suitable weight to the $\mathrm{K_L}$ events, which depends on the decay vertex position and momentum of the kaon. In this way the experiment does not need an accurate Monte Carlo simulation of the detector, the acceptances cancel out in the double ratio R, and the residual correction to be applied is $< 0.5\%$. The price for that is the increase of the statistical error up to 40% for a decay region of 4 $\mathrm{K_S}$ lifetimes.

Background study: the background to the $\pi^+\pi^-$ events is mostly due to the $\mathrm{K_L}$ semileptonic decays. The electron rejection is made by a E/p cut, the muon's by cuts on the muon–veto. Two variables are well suited to study the background. One is related to the kaon transverse momentum squared ${P_T}^2$, being, in fact, a particular projection of the kaon momentum with similar distribution for $\mathrm{K_L}$ and $\mathrm{K_S}$. The other is the charged pion pair invariant mass $M_{\pi\pi}$. Selected samples of $K_{\mu3}$ and K_{e3} decays are used to parametrize the background shape in the (${P_T}^2$, $M_{\pi\pi}$) plane and extrapolate it into the signal region. Fig. [1](a) shows the ${P_T}^2$ distribution for background and candidate events. The residual background fraction is measured to be $\leq 3 \times 10^{-3}$.

The main background to the neutral $\pi^0\pi^0$ events is due to the $\mathrm{K_L} \rightarrow 3\pi^0$ decay with two missing photons. The four recontructed photons are paired in order to get the value of the two–photon invariant masses $M_{\gamma_i\gamma_j}$ closest to the π^0 mass M_{π^0}. The R_{ell} estimator, which represents the best χ^2 which gives $M_{\gamma_i\gamma_j} = M_{\pi^0}$, is used to evaluate the neutral background. Fig. [1](b) shows the R_{ell} distributions for $\mathrm{K_S}$ and $\mathrm{K_L}$ events. A background fraction $\leq 10^{-3}$ is measured for weighted $\mathrm{K_L}$ events.

4 The 1998 data taking

In 1998 the NA48 experiment run for about 110 days at nominal beam intensity. A total of 65 TB of data were recorded and reprocessed. About 2 millions of CP–violating $\mathrm{K_L} \rightarrow \pi^0\pi^0$ decays were collected.

Several detector improvements have been implemented before the 1998 data taking. A new light carbon fibre beam pipe has been installed, to reduce the showers produced by interactions in the pipe walls. All the blocking capacitors have been replaced in the LKr calorimeter, which has been operating at an electric field of 3 KV/cm, with a 20% signal gain with respect to 1997. New processors have been installed in the charged trigger system in order to handle higher trigger rates, and reduce deadtime. The data acquisition system has been upgraded by using a PC farm for both data handling and event building. A data transfer rate of 20 MB/s and an overall data acquisition system capability of 120 MB/s, over the burst duration, have been achieved.

The NA48 experiment will take $\mathrm{Re}(\varepsilon'/\varepsilon)$ data in the years 1999 and 2000, about 120 days per year.

5 The rare decays analysis

Some relevant rare kaon decays can be studied with the NA48 detector.

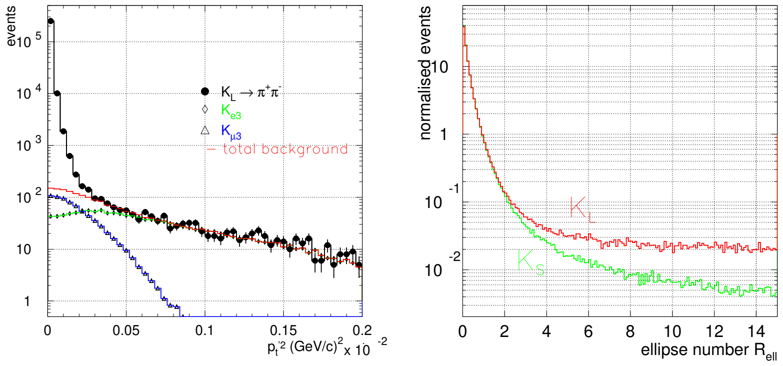

Figure 1: (a): $P_T{}^2$ distribution for $\pi^+\pi^-$ candidate and background events; (b): Rell distribution for $\mathrm{K_S}$ and $\mathrm{K_L}$ into $\pi^0\pi^0$ candidate events

$\mathrm{K_L} \rightarrow e^+e^-\gamma$ *decay:* a sample of 6864 decays has been observed with the NA48 detector in 1997, with an estimated background of 10 events. The branching ratio is $B.R. = (1.06 \pm 0.02_{stat} \pm 0.02_{syst} \pm 0.04_{theor}) \times 10^{-5}$. The parameter α_{K^*}, describing the relative strength of the two contributing amplitude to the decay through intermediate pseudoscalar or vector meson, is measured to be $\alpha_{\mathrm{K}^*} = (-0.36 \pm 0.06_{stat} \pm 0.02_{syst})$. The analysis on 1998 data is in progress, the expected statistics being 5 time larger than in 1997.

The $\mathrm{K_L} \rightarrow \pi^+\pi^-e^+e^-$ *decay:* a large asymmetry is expected in the angle between the (π^+, π^-) and the (e^+, e^-) planes, due to CP and T violation. About 500 events are expected in the 1998 data statistics. A very preliminary value of the branching ratio $B.R. = (3.13 \pm 0.23_{stat}) \times 10^{-7}$ is measured [10].

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