PRELIMINARY RESULT ON DIRECT CP VIOLATION FROM NA48 1998 DATA

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Abstract

We present a new result on direct CP violation based on the data collected in 1998 by the NA48 experiment at CERN. Comparing the decay rates of the neutral kaons K_S and K_L into $\pi^+\pi^-$ and $\pi^0\pi^0$, we obtain a preliminary measurement of $Re(\varepsilon'/\varepsilon) = (12.2 \pm 2.9(\mathrm{stat.}) \pm 4.0(\mathrm{syst.})) \times 10^{-4}$.

[1]Cagliari, Cambridge, CERN, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Orsay, Perugia, Pisa, Saclay, Siegen, Torino, Vienna, Warsaw.

1 Direct CP violation

CP violation was discovered in 1964 [1], through the decay of long-lived neutral kaons into a CP-even state : $\pi^+\pi^-$. The dominant part of CP violation was established to come from the $K^0 - \overline{K^0}$ mixing. This main component is parametrized by the ε parameter, which gives the size of the small mixing of CP eigenstates (K_1 and K_2) in the physical states K_S and K_L.

In the standard model, this violation by mixing is authorized by the irreducible phase of the quark mixing matrix [2], through $K^0 - \overline{K^0}$ oscillation box diagrams. Through penguin diagrams, the standard model also authorizes **direct CP violation**, that is a violation occuring directly in the decay process. This new type of CP violation is parametrized by the ε' parameter and can be probed by the double ratio method :

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

Precise non-zero measurements of $Re(\varepsilon'/\varepsilon)$ can check the standard model against other interpretations such as the superweak model [3] ($\varepsilon' = 0$) or contributions from physics beyond the standard model. For a review of standard model computations see reference [4].

Previous results from E731 [5] $Re(\varepsilon'/\varepsilon) = (7.4 \pm 5.9) \times 10^{-4}$ and NA31 [6] $Re(\varepsilon'/\varepsilon) = (23. \pm 6.5) \times 10^{-4}$ are marginally consistent and do not allow to conclude for direct CP violation. KTeV and NA48 experiments are designed to measure $Re(\varepsilon'/\varepsilon)$ with a 2.10^{-4} accuracy. The first KTeV result [7] $Re(\varepsilon'/\varepsilon) = (28.0 \pm 4.1) \times 10^{-4}$ and NA48 result [8] $Re(\varepsilon'/\varepsilon) = (18.5 \pm 7.3) \times 10^{-4}$ point to the existence of direct CP violation.

In this paper, we report a new measurement of $Re(\varepsilon'/\varepsilon)$ by the NA48 experiment, based on the data collected in 1998. This result is still preliminary.

2 The NA48 experiment

The method used by NA48 to measure $Re(\varepsilon'/\varepsilon)$ is to collect the four decay modes of equation (1) simultaneously, from a common decay region, so that the flux, acceptances and efficiencies cancel in the double ratio. To do so, two simultaneous and collinear beams of K_S and K_L are required.

2.1 The beams

Figure 1 shows a schematic layout of the NA48 beams.

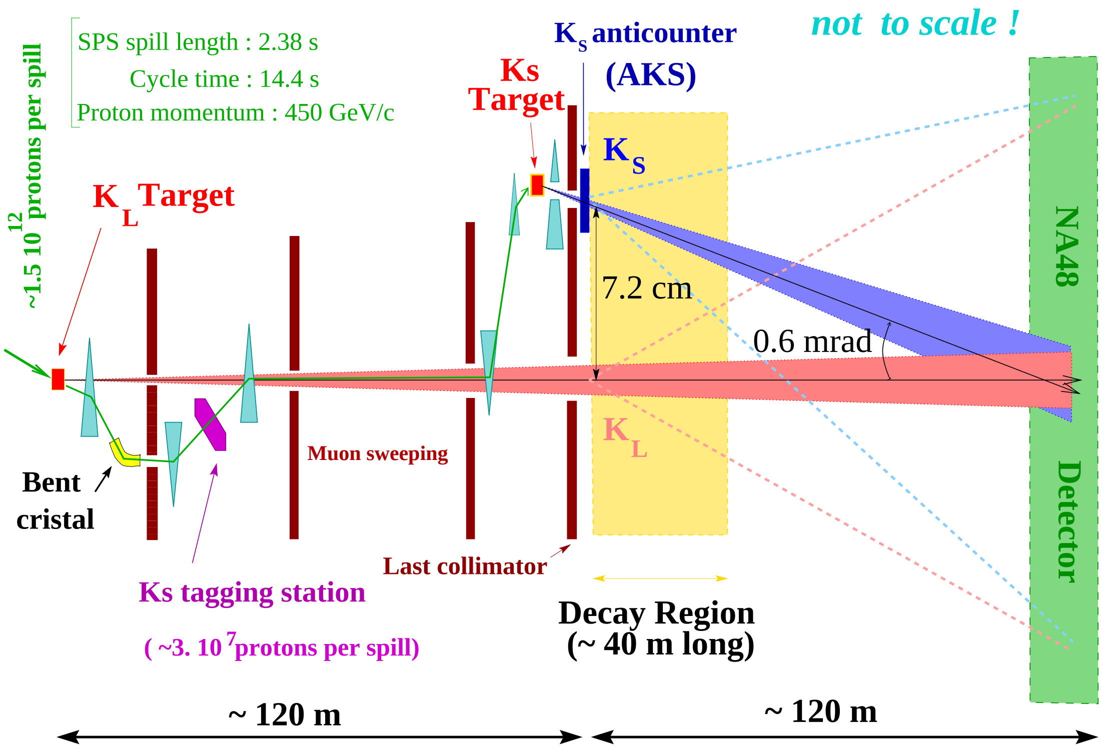

Figure 1: *NA48 collinear and simultaneous beams.*

The K_L beam is produced by a primary proton beam of 450 GeV provided by the CERN SPS, and impinging on a first target located 126 m upstream the decay region. A small fraction of the protons exiting the first target is channeled and transported to a second target located 120 m downstream. Thus, $\pi\pi$ decays detected in the decay region belong to the K_S (K_L) component of the beams produced on the close (far) target.

The second target is located 7.2 cm above the K_L beam axis and the last collimators impose that the two beams converge at the centre of NA48 detector, with a relative angle of 0.6 mrad.

An anticounter (AKS) is installed in the K_S beam line to define precisely the beginning of the decay region. This apparatus is also used to check the global distance and energy scale.

The distinction between K_S and K_L beams is provided by the coincidence of the event time and the time of the protons measured by the tagging station on their way to the K_S target.

2.2 The detectors

The main detectors of NA48 are a magnetic spectrometer for the reconstruction of the $\pi^+\pi^-$ events, and a liquid krypton (LKr) electromagnetic calorimeter for the reconstruction of $\pi^0\pi^0 \to 4\gamma$ events.

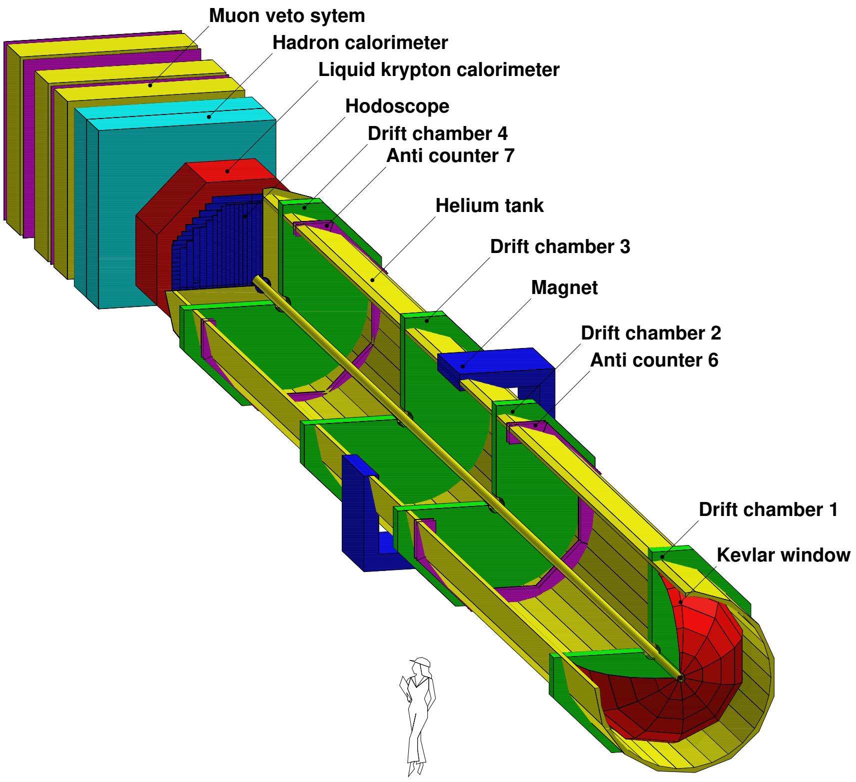

Figure 2: *NA48 detectors.*

The **spectrometer** is made of four large drift chambers and a dipole magnet providing a 265 MeV/c momentum kick. The space-point resolution of a chamber is 90 μm and the vertices are reconstructed with a 2 mm transverse and 50 cm longitudinal resolutions. The transverse resolution allows to separate the beams, which cannot be done in the neutral mode. Therefore, we have to use the proton tagging to distinguish K_S and K_L.

The momentum resolution is given by the equation below and leads to a 2.5 MeV/c^2 resolution on the reconstructed kaon mass.

$$\sigma(p)/p \simeq 0.5\% \oplus 0.009 \times p(GeV/c)\% \qquad (2)$$

The **LKr calorimeter** is made of 13212 cells with a $2 \times 2\ cm^2$ surface and a tower structure 125 cm long. Spacer plates impose a projective geometry pointing to the decay region, and a ± 48 mrad accordion geometry in order to avoid electrode effects. The energy resolution measured on 1998 data is given by the following formula. The reconstructed π^0 mass resolution reaches 1.1 MeV/c^2.

$$\frac{\sigma(E)}{E} \simeq \frac{3.2\%}{\sqrt{E}} \oplus \frac{100 MeV}{E} \oplus 0.5\% \tag{3}$$

The time measurements of the LKr have a resolution around 270 ps and are used in comparison with the proton times measured by the tagger to distinguish K_S and K_L. For the $\pi^+\pi^-$ decays, the time is provided by an hodoscope, made of two planes of scintillators and giving a resolution of 200 ps.

The NA48 detector is completed by an hadronic calorimeter, a set of three muon veto planes and seven rings of anti-counters surrounding the decay region. Figure 2 shows the various detectors.

3 The 1998 run and analysis

With respect to 1997 data [8], few improvements have been made during 1998 data taking :

- Improvements in the charged trigger and data acquisition systems allowed to raise the proton intensity by 40%, reaching 1.4×10^{12} per pulse.
- The LKr calorimeter was operated at 3 kV (rather than 1.5 kV in 1997) and fully connected to the high voltage.
- A lighter beam pipe was put through the detector to diminish the accidental activity.

The analysis is made with the same cuts as for 1997 data.

3.1 $\pi^+\pi^-$ selection and background rejection

The main sources of background are made of Ke3 and Kμ3 decays in the K_L beam. To select $\pi^+\pi^-$ events, the following criteria are requested :

- Muon rejection : each track finds no hit in the muon veto.
- Electron rejection : each track deposits less than 80 % of its energy in the LKr calorimeter ($E_{LKr}/P_{DCh} < 0.8$).

- The $\pi^+\pi^-$ invariant mass ($m_{\pi\pi}$) is consistent with the kaon mass within three standard deviation.

- The transverse momentum is small : $p_t^2 < 200\ (MeV/c)^2$.

The residual background is estimated from the data, by fitting the K_L distribution as the sum of three contribution : pure $\pi^+\pi^-$ events given by K_S identified vertices (background free), Ke3 and Kμ3 distributions given by identified electron or muon in the detectors. The fit is made in control regions in the $m_{\pi\pi}$ versus p_t plane and extrapolated under the signal region. The resulting background is equal to $(19 \pm 3) \times 10^{-4}$, dominated by Ke3 events.

The result of the fit is shown for the p_t variable on figure 3. The high p_t remaining distribution corresponds to scattered kaons on the K_L collimators. These events are rejected by the p_t cut, but since there is no similar cut in the neutral mode, a correction must be applied to the double ratio. It is estimated to be $(-9.9 \pm 3.3) \times 10^{-4}$.

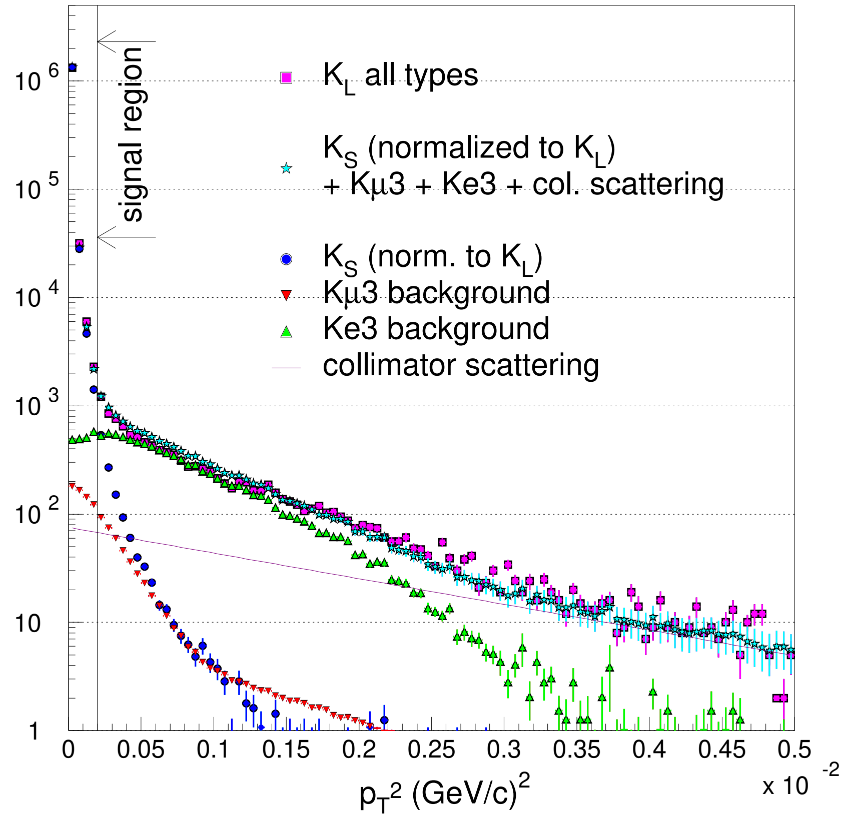

Figure 3: *Transverse momentum distributions.*

3.2 $\pi^0\pi^0$ selection and background rejection

Background to the $2\pi^0$ mode is dominated by $K_L \to 3\pi^0$ events. To select good events, we impose the kaon mass to any set of four in-time photons, and reconstruct the distance D of the decay to the calorimeter $D = \sqrt{\sum E_i E_j \times (r_{ij})^2}/m_k$, where E_i are the cluster energies and r_{ij} their distances. We then compute the $\gamma\gamma$ invariant masses and look for a $2\pi^0$ combination. The result is shown on figure 4 left. The two masses being correlated, we build up a χ^2 variable out of the sum and the difference :

$$R_{ell} = \left(\frac{\frac{m_1+m_2}{2} - m_{\pi^0}}{\sigma_+}\right)^2 + \left(\frac{\frac{m_1-m_2}{2}}{\sigma_-}\right)^2 \tag{4}$$

To select good events, we request that this variable is less than 13.5. To diminish the background, events occuring with an in-time ($\pm 3\ ns$) cluster are also rejected.

The remaining background is estimated by comparing the K_S and K_L distributions (figure 4 right). The difference is computed for high values of R_{ell} and extrapolated under the signal region. The resulting background estimation is $(6.6 \pm 2.0) \times 10^{-4}$.

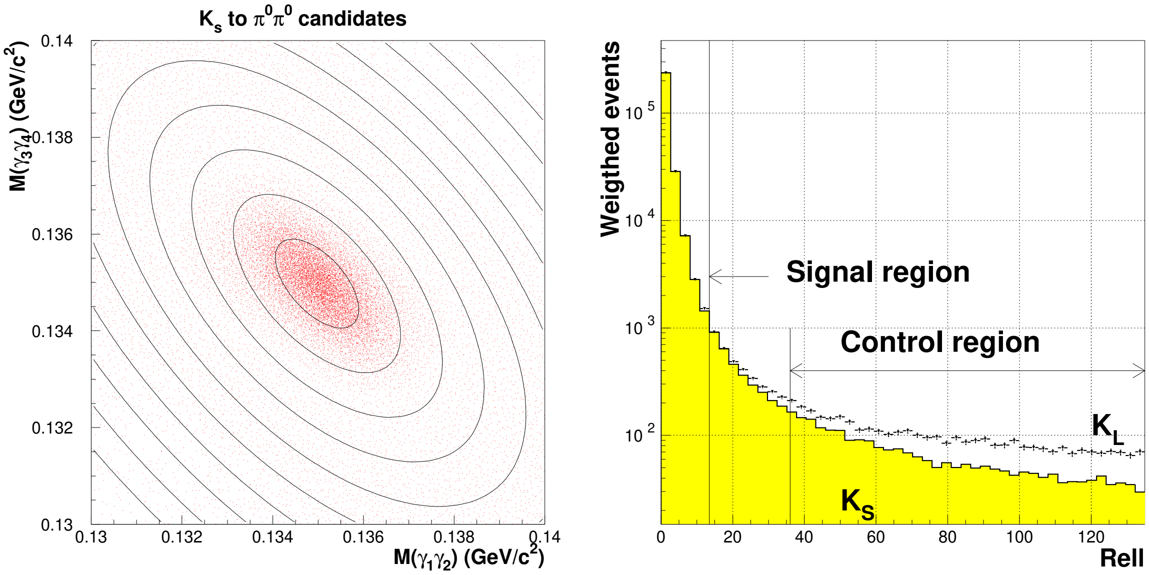

Figure 4: *Left : Reconstructed π^0 masses for $K_S \to \pi^0\pi^0$ candidates. Right: R_{ell} variable for K_L candidates and normalized $K_S \to \pi^0\pi^0$, the difference being due to $3\pi^0$ background.*

3.3 K_S and K_L beam distinction

Using vertex identified $\pi^+\pi^-$ events we can study the tagging performances. Figure 5 shows the distribution of the nearest proton time with respect to the event time, separately for K_S and K_L.

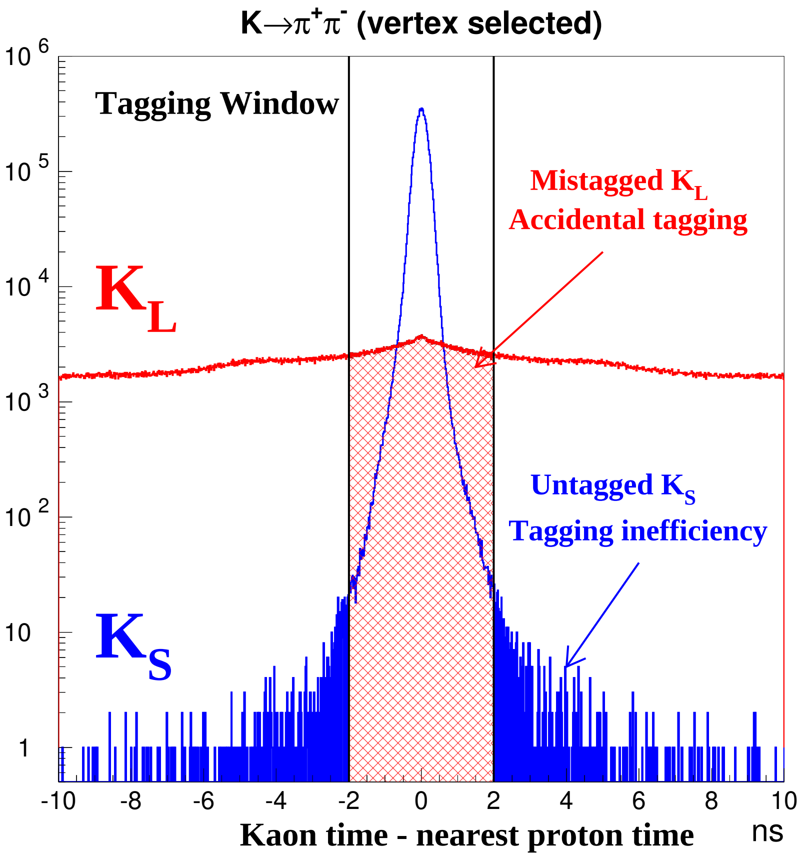

Figure 5: *Tagging of $K_{S,L} \to \pi^+\pi^-$ events.*

Choosing a 4 ns wide tagging window, the K_S tagging inefficiency is measured to be $\alpha_{SL}^{+-} = (1.97 \pm 0.05) \times 10^{-4}$, while the K_L accidental tagging probability is $\alpha_{LS}^{+-} = (11.05 \pm 0.01)\%$. Different probabilities in the neutral mode could induce a bias in the double ratio.

The inefficiency difference is measured to be $|\alpha_{SL}^{+-} - \alpha_{SL}^{00}| < 0.5 \times 10^{-4}$ by comparing the charged and neutral reconstructed times of neutral events including a photon conversion. The induced uncertainty on R is $\pm 3 \times 10^{-4}$.

The accidental tagging probability difference is measured using the probabilities of having a proton in out-of-time windows for K_L charged and neutral events.

A correction is applied to account for rate differences between in-time and out-of-time windows using vertex identified $K_L \to \pi^+\pi^-$ and $K_L \to 3\pi^0$. The difference is measured to be $\alpha^{00}_{LS} - \alpha^{+-}_{LS} = (0.3 \pm 4.2) \times 10^{-4}$, the uncertainty being limited by the $K_L \to 3\pi^0$ statistics. The corresponding correction to the double ratio is $\Delta R = (0.6 \pm 8.4) \times 10^{-4}$.

3.4 Weighting procedure and acceptance correction

The principle of NA48 is to make the acceptance to cancel between K_S and K_L events in the double ratio. The beams being almost collinear, the acceptance of the detector is similar at a given longitudinal position and for a given energy.

To make the longitudinal distributions look similar, we weight each K_L event by a factor $exp(-z \times (\frac{1}{\Lambda_S} - \frac{1}{\Lambda_L}))$, where z is the reconstructed position and $\Lambda_{S,L}$ are the decay length at the associated energy. This weighting procedure is illustrated by figure 6, showing the longitudinal distributions of K_S, K_L and weighted K_L events.

The accepted decay region starts at the AKS position and is $3.5 \times c\tau_S$ long. The origin is defined by an AKS veto cut for K_S events and by a cut on the reconstructed z position for K_L events.

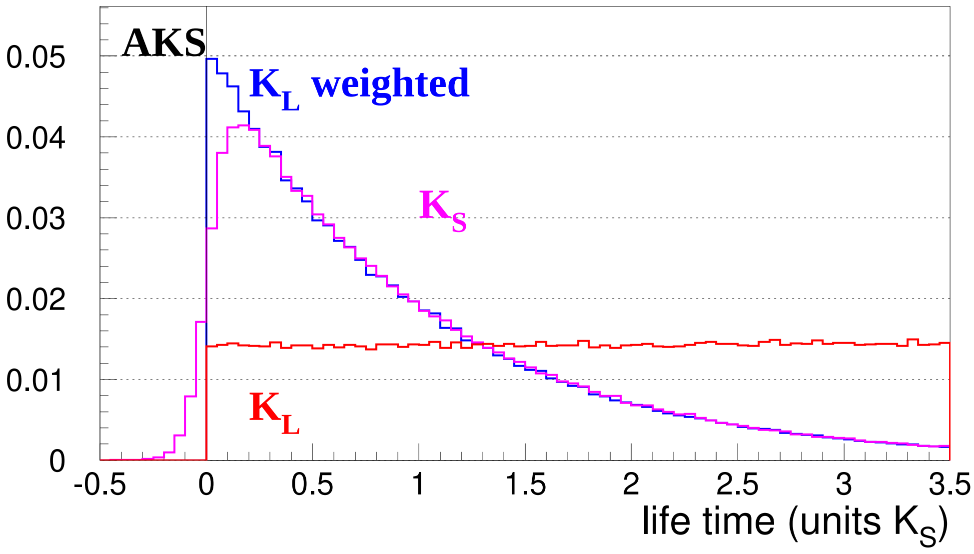

Figure 6: *Weighting procedure.*

The energy spectra of the two beams are similar in the considered range (70-170 GeV) and we perform the entire analysis in energy bins of 5 GeV to get rid of the small differences.

The beams being not exactly collinear, small acceptance differences remain. We compute them using a Montecarlo simulation of the 4 modes. The average correction is $\Delta R = (30 \pm 7(\mathrm{MC\ stat.}) \pm 6(\mathrm{syst.})) \times 10^{-4}$.

The advantage of the weighting procedure is to keep this correction to a low level : less than 1 % in all energy bins, while it reaches 13 % without weighting. The price to pay is an increase of 35 % of the K_L statistical error.

3.5 Trigger efficiencies and dead-times

The trigger for the $\pi^+\pi^-$ mode is a two-levels system. The first level is made of the coincidence of three components : a 2-track topology in the hodoscope and in the first drift chamber, and a minimum energy deposit in the calorimeters. The second level is based on a reconstruction of the vertices and $\pi^+\pi^-$ invariant mass by a real-time processing farm. The efficiency of these systems was continuously measured through downscaled control triggers : 99.4 % and 97.7 % for the levels 1 and 2.

Comparing the efficiencies for K_S and K_L events leads to the correction on the double ratio : $\Delta R = (-1 \pm 11) \times 10^{-4}$.

For the $\pi^0\pi^0$ mode, the trigger is based on the LKr signals. A fully pipelined system computes every 25 ns the number of peaks, the kaon energy and vertex position. Its efficiency is $(99.93 \pm 0.02)\%$ and cannot lead to a significant bias on R.

The various dead-times of the experimental components are monitored and applied to all modes in order to symmetrize the loss of events. A loss of ~ 4 % comes from the charged trigger and a loss of ~ 25 % arise from an overflow condition in the drift chamber read-out system.

3.6 Reconstruction bias

The precise knowledge of the absolute energy scale of the calorimeter is crucial since the z position of $\pi^0\pi^0$ events is given by an energy measurement. The energy scale is fixed by fitting the known AKS position. The accuracy is estimated to be $\pm 5 \times 10^{-4}$, corresponding to $\pm 3 \times 10^{-4}$ on R. Other sources of systematic error from the neutral reconstruction are estimated : calorimeter non-linearity($\pm 5 \times 10^{-4}$), non-gaussian tails in energy reconstruction ($\pm 3 \times 10^{-4}$), uncertainty on transverse energy scale ($\pm 3 \times 10^{-4}$),... All together, these effects lead to a $\pm 10 \times 10^{-4}$ uncertainty on R.

The charged reconstruction bias is estimated to have the following effect on R : $(+2 \pm 2) \times 10^{-4}$.

3.7 Accidental activity

Simultaneous data-taking and similar instantaneous intensity of the two beams make the effect of accidental activity similar between K_S and K_L.

Remaining geometrical effects are estimated by overlaying random-triggered events on top of good candidates. Counting gains and losses gives a correction of $\Delta R = (2 \pm 6) \times 10^{-4}$.

Residual K_S/K_L intensity variations can induce a bias if events are lost in charged and neutral mode in a different way. A conservative limit on these effects is computed : $\Delta R < 10 \times 10^{-4}$.

4 The result

The collected statistics in the four modes are reported in table 1, after correction for mistagging. The associated statistical error on R is 17.3×10^{-4}, taking the weighting procedure into account.

Table 1: *Event statistics (million of events)*

$K_L \to \pi^0\pi^0$	1.14	$K_L \to \pi^+\pi^-$	4.87
$K_S \to \pi^0\pi^0$	1.80	$K_S \to \pi^+\pi^-$	7.46

Table 2 summarizes the various systematic effects. The overall correction applied to the raw double ratio is $(37 \pm 24) \times 10^{-4}$.

Table 2: *Summary of systematic uncertainties*

Systematic effect	Correction (10^{-4})	Uncertainty (10^{-4})
Accidental tagging	+1	8
Tagging inefficiency	—	3
$\pi^+\pi^-$ background	+19	3
Beam scattering	– 10	3
$\pi^0\pi^0$ background	– 7	2
$\pi^+\pi^-$ trigger	– 1	11
Acceptance correction	+31	9
$\pi^0\pi^0$ reconstruction	—	10
$\pi^+\pi^-$ reconstruction	+ 2	2
Accidental activity	+ 2	12
Total	+37	24

Figure 7 displays the double ratio measured in each energy bin. Averaging the values between 70 and 170 GeV with an unbiased estimator leads to the measurement of the double ratio :

$$R = 0.99267 \pm 0.00173(\mathrm{stat.}) \pm 0.00238(\mathrm{syst.}) \tag{5}$$

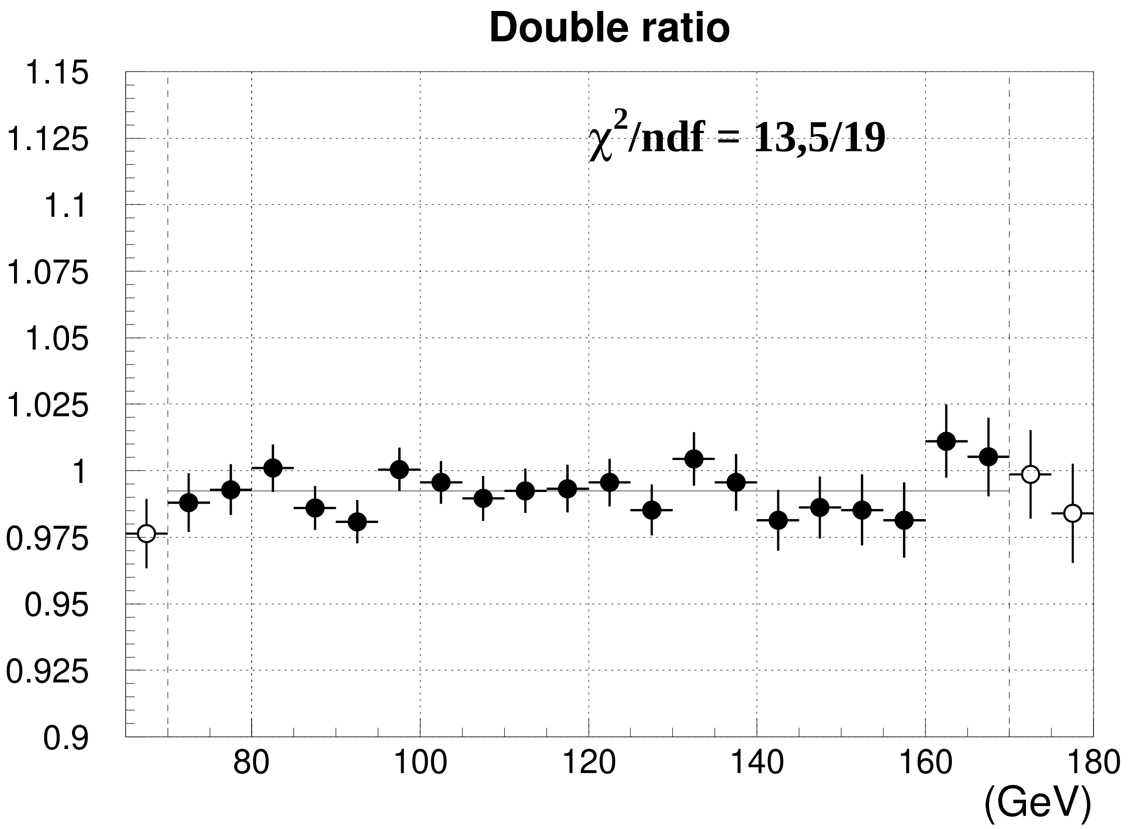

Figure 7: *Double ratio measurements as fonction of energy.*

This preliminary result corresponds to the following value of the direct CP violation parameter :

$$Re(\varepsilon'/\varepsilon) = (12.2 \pm 2.9(\mathrm{stat.}) \pm 4.0(\mathrm{syst.})) \times 10^{-4} \tag{6}$$

Many checks have been performed to verify the stability of this result with respect to the various analysis criteria.

5 Prospects and conclusions

This new preliminary result is in agreement with the published NA48 result based on the 1997 sample. Taking into account the small correlated systematic error, the two results average to :

$$Re(\varepsilon'/\varepsilon) = (14.0 \pm 4.3) \times 10^{-4} \tag{7}$$

which confirms the existence of direct CP violation in the two pion decay of neutral kaons.

The analysis of 1998 data is continuing and some systematics are expected to be reduced. The analysis of 1999 sample whose statistics is twice larger has also started.

The completion of the $Re(\varepsilon'/\varepsilon)$ program is delayed because of the implosion of the carbon fiber beam pipe by the end of 1999, which destroyed the four drift chambers. The collaboration has already been granted to rebuild the chambers in order to complete the program with the run of 2001. The runs of 2000 (without spectrometer) and 2001 will be mostly devoted to systematic studies.

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