THE FINAL RESULT ON DIRECT CP VIOLATION FROM THE NA48 EXPERIMENT

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The NA48 experiment at CERN has recently obtained the final result on the ε'/ε parameter, that quantifies direct CP violation in the K^0–$\bar{K}^0$ system. The total data sample, acquired during five years of data–taking, corresponds to 5.3 million $K_L \to \pi^0\pi^0$ decays. The result, $Re(\varepsilon'/\varepsilon) = (14.7 \pm 2.2) \times 10^{-4}$, confirms unambiguously the occurrence of direct CP violation. Converting this number in a precision test of the Standard Model picture of CP violation is an open challenge for non-perturbative QCD calculations.

1. The measurement of $\mathrm{Re}(\varepsilon'/\varepsilon)$

The CP–violating decay of the long–lived neutral kaon to two pions is dominated by the CP–conserving decay of the small CP=+1 component K_1, namely by the indirect CP violation quantified by the well-know ε parameter. However, it can also proceed through a direct CP violation in the decay $K_2 \to \pi\pi$, that is usually expressed by the ε' parameter.

After the first unexpected observation of this decay in 1964 [1], a natural explanation of the suppression of the direct component was provided by the superweak model [2], that confines CP violation to the $\Delta S = 2$ transitions, thus predicting $\varepsilon' = 0$. In 1973, in order to include CP violation in the framework of the Standard Model (SM), Kobayashi and Maskawa anticipated the existence of the third quark generation [3]. Since in the SM picture a non–zero value of ε' is allowed, large experimental efforts were devoted in the last 20 years to the measurement of the double ratio

$$\mathrm{R} = \frac{\Gamma(K_L^0 \to \pi^0\pi^0)}{\Gamma(K_L^0 \to \pi^+\pi^-)}\frac{\Gamma(K_S^0 \to \pi^+\pi^-)}{\Gamma(K_S^0 \to \pi^0\pi^0)} \simeq 1 - 6 \times \mathrm{Re}\left(\frac{\epsilon'}{\epsilon}\right)$$

*supported by the European Community through a Marie Curie Fellowship under contract number HPMF–CT–2000–00893

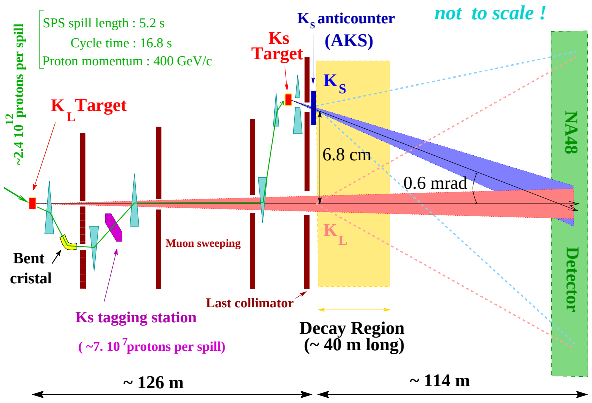

Figure 1. A sketch of the simultaneous K_L and K_S beam lines. The fiducial region for K^0 decays begins more than 12 K_S lifetimes downstream the primary target in order to obtain an almost pure K_L beam. The K_S beam is obtained by extracting a small fraction of the protons emerging from the primary target and transporting them to a second target, located immediately before the decay region. The two beams converge with a small angle in order to be overlapped in the middle of the central detector.

that allows a precise determination of ε'/ε thanks to the cancellation of many experimental uncertainties.

The NA48 experiment, installed at the CERN SPS, measures the double ratio by counting simultaneously the four decay modes from the same fiducial region using two high–intensity and quasi–collinear K_S and K_L beams (see figure 1). The two beams illuminate in a very similar way the central detector, based on a large magnetic spectrometer and on a liquid Krypton homogeneous calorimeter, where the $\pi^+\pi^-$ and $\pi^0\pi^0$ decays are reconstructed [a]. In order to distinguish K_S from K_L events, a $\pm$ 2 ns coincidence is required between the event time and the passage of a proton in a tagging station located along the K_S beam line. The two main differences between K_S and K_L decays are minimized offline:

- the analysis is performed in 20 kaon energy bins between 70 and 170 GeV to account for the different energy spectra;
- K_L events are weighted according to the K_S lifetime to equalize the effective detector illumination from the two beams.

Finally, a set of small (<0.3 % by first principles) corrections have to be applied to account for remaining biases due to backgrounds, residual acceptance difference, $K_L \leftrightarrow K_S$ mistagging, intensity and reconstruction effects.

[a]for a more detailed description of beam lines and detectors see ([4])

2. The 2001 run

The bulk of the NA48 ε' data was collected during the 1998 and 1999 runs, when 3.3×10^6 $K_L \rightarrow \pi^0\pi^0$ decays (the mode limiting the statistical accuracy) were recorded, leading to the published result[4] $\mathrm{R}e(\varepsilon'/\varepsilon) = (15.0 \pm 2.7) \times 10^{-4}$. The 2000 run was used to perform some cross-checks and other physics measurements on neutral decay modes, the spectrometer being unavailable after that all its four drift chambers were damaged in an accident occurred in November 1999. Meanwhile, the chambers were rebuilt and reinstalled in time for the 2001 data–taking.

Some of the most crucial systematic corrections on the double ratio for the 1998/1999 analysis were due to rate effects, namely the residual differences of instantaneous intensity seen by K_S and K_L events (leading to possible differences in accidental activity and trigger inefficiency) or by neutral and charged events (leading to possible differences in the mistagging probabilities, which depend from the K_S proton rate seen by the reconstructed events). For this reason the 2001 data were taken with different beam conditions: profiting of the possibility to extend the SPS duty cycle from 2.4/14.4 to 5.2/16.8 s, we could decrease the average instantaneous intensity by about 30 % while keeping about the same typical per day event statistics. Concurrently the proton energy was decreased from 450 to 400 GeV.

The 2001 data allowed to increase our sample by almost 50 % (1.55×10^6 $K_L \rightarrow \pi^0\pi^0$) and to perform a major systematic check of our result, by repeating the measurement at a different beam intensity and after rebuilding all the spectrometer drift chambers. As expected, all intensity–related effects were reduced: for example, the efficiency of the level–2 charged trigger increased from 98.3% to 99.2% and the probability of an accidental coincidence between a K_L event and a K_S proton was reduced from 10.6% to 8.1%. In the following table, corrections and systematic uncertainties on R (in units $= 10^{-4}$) are compared between the 1998/1999 and 2001 analysis:

	2001			1998/1999		
event statistics		±	14.7		±	10.1
$\pi^0\pi^0$ reconstruction		±	5.3		±	5.8
Acceptance	21.9	±	5.3	26.7	±	5.7
Trigger inefficiency	5.2	±	3.6	-3.6	±	5.2
Accidental losses		±	3.3		±	4.3
Accidental tagging	6.9	±	2.8	8.3	±	3.4
Tagging inefficiency		±	3.0		±	3.0
Backgrounds	-0.2	±	4.1	1.4	±	4.1
Others	1.2	±	2.8	1.1	±	2.8
Total systematic	35.0	±	11.1	35.9	±	12.6

Accidental effects could be better constrained also thanks to new beam monitors, allowing to measure the integrated intensity on different time scales (from 0.2 to 15 μs). The 2001 result was finally limited by the statistical error:

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (13.7 \ \pm \ 2.5(\mathrm{stat}) \pm \ 1.8(\mathrm{syst})) \times 10^{-4}$$

3. Final Result

The excellent agreement of the 2001 result with the previous runs is shown in figure 2. Combining all the data we get to the final result

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (14.7 \ \pm \ 1.4(\mathrm{stat}) \pm \ 1.7(\mathrm{syst})) \times 10^{-4}$$

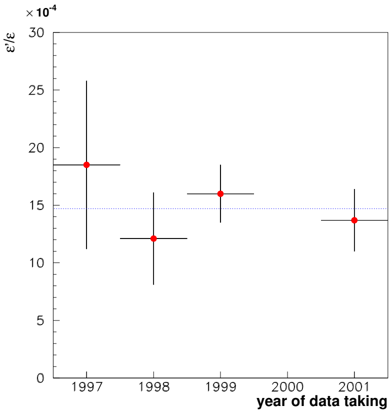

Figure 2. Comparison of ε'/ε results obtained by NA48 in different years.

which by itself establishes direct CP violation with a significance of 6.7 σ. The comparison of this number with the SM prediction is presently limited by the theoretical uncertainty on the non–perturbative contributions related especially to the strong and electroweak penguin diagrams. However, the precision of this result, as well as the KTEV one[5], stimulated in the last years a vast theoretical effort in these challenging calculation, leading to promising progresses, particularly in the domain of lattice QCD. The most recent predictions[6] seem to prefer values typically in the range (-10 – 10)$\times 10^{-4}$, though the theoretical uncertainties still do not allow to claim for any disagreement with the experiments.

References

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