THE FUTURE NA48 PROGRAMS AT CERN

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Two proposals have been approved at CERN to extend the NA48 physics program after the end of the $Re(\epsilon\,'/\epsilon)$ measurement. The first one will study rare K_S and hyperon decays physics, using an intense K_S beam. The second one will investigate direct CP violation in charged kaon decay, using simultaneous K^+/K^- beams.

1 The NA48 physics program

The NA48 experiment has been designed to measure the direct CP violation parameter $Re(\epsilon\,'/\epsilon)$ with a precision of $\sim\ 2\times10^{-4}$. The new NA48 result based on the 1997–1999 data samples is[1, 2]:

$$Re(\epsilon\,'/\epsilon)\ = (15.3 \pm 2.6)\times10^{-4}$$

This value clearly establishes the occurrence of direct CP violation in the neutral kaon system. The 2001 data taking of NA48 was devoted to complete the $Re(\epsilon\,'/\epsilon)$ physics program.

The quality of the simultaneous K_L and K_S beams, the high resolution detector, the high capability trigger and data acquisition systems allow NA48 to study, in parallel with $Re(\epsilon\,'/\epsilon)$, rare neutral kaon decays and neutral hyperon decays.

Several results, based on the analysis of the data collected in the ϵ'/ϵ runs in 1997–1999 and in dedicated runs with a single intense K_S beam, have been published[3–6]. The typical fluxes available in ϵ'/ϵ running mode were 2×10^7 K_L and 3×10^2 K_S per SPS pulse (see Tab. 1). Those values correspond to the SES (single–event–sensitivity) of 3×10^{-10} for K_L decays and of 1.5×10^{-7} for K_S decays in one year of data taking (120 days at 50% efficiency) assuming an overall acceptance of 10% after the analysis cuts.

In 1999 a two days run was devoted to exploit the NA48 technique to make an intense K_S beam. The proton intensity on the K_S target was increased by a factor ~ 200, and the K_L beam was switched off. The total number of K_S decays reconstructed in two days was about 2.3×10^8, corresponding to a SES of 4×10^{-8} at a

10% acceptance. This performance is equivalent to several years of operation with the double beams of the ϵ'/ϵ mode. The data collected during this short test run allow to substantially improve measurements of rare K_S [4, 5] and neutral hyperon decays.

Following the above experience, a new experiment has been proposed [7] for a high sensitivity investigation of K_S and neutral hyperon decays, using an intense K_S beam and the existing NA48 detector, for an extension of the NA48 program after the end of the ϵ'/ϵ measurement. This addendum to the NA48 proposal was approved in 2000 as NA48/1.

In the year 2000 the NA48 experiment took data without magnetic spectrometer, which was seriously damaged by the implosion of the carbon fiber beam pipe in 1999, and was restored only for the 2001 run. For that reason, in the 2000 run, only neutral decays have been recorded. About 40 days were spent to run with an intense K_S beam, at optimized beam conditions. The proton momentum was reduced from 450 GeV/c to 400 GeV/c, and the kaon production angle was decreased to compensate the beam momentum loss. The proton intensity on the K_S target was $\sim 9 \times 10^9$ per SPS pulse, with a spill time of of 3.2 s every 14.4 s, longer than the usual one in order to reduce the instantaneous rate in the detector. About 10^{10} K_S decays have been collected in the fiducial volume of the experiment, the data analysis is in progress.

A second addendum to the NA48 proposal was also approved in 2000 as NA48/2. It aims at the precision measurement of charged kaon decay parameters [8]. A new beam setup is proposed, with simultaneous charged kaon beams and an upgraded detector, in order to measure a possible direct CP violation signal in charged kaon decays into three pions and study other $K^{\pm}$ decays.

2 NA48/1: the high intensity K_S proposal

A data taking of about 120 days has been required to run NA48/1 in the year 2002. Minor modifications to the present K_S beam line are foreseen to optimize the experimental conditions. The main beam parameters of the K_S beam proposed in 2002 are compared

Table 1: **Parameters of the intense K_S beam proposed for the 2002 run of NA48/1 compared to the $K_S + K_L$ beams of the ϵ'/ϵ mode**

Beam	$K_L + K_S$		K_S **beam**
Year	**1999**		**2002**
SPS momentum (GeV/c)	450		400
Duty Cycle (s/s)	2.5/14.4		5.0/19.2
Protons per pulse on target	1.5×10^{12}	3×10^{7}	1×10^{10}
Production angle α (mrad)	+2.4	-4.2	-2.5
Total beam flux K's/pulse	$\sim 2 \times 10^{7} + \sim 3 \times 10^{2}$		$\sim 1.5 \times 10^{5}$
Mean momentum $< P_K >$ (GeV/c)	~ 110		~ 115
Useful momentum range ΔP_K (GeV/c)	70–170		40–240
K-decays/pulse in Δp_K	$1.0 \times 10^{5} + 1.8 \times 10^{2}$		1.1×10^{5}
K-decays/year in Δp_K (50% $\times$ 120 days)	$3.6 \times 10^{10} + 6.5 \times 10^{7}$		3.0×10^{10}

to the double beams of the ϵ'/ϵ mode in Tab. 1. The expected rates are about two times higher than those of the ϵ'/ϵ mode.

The use of the longest possible SPS duty cycle is required, in order to improve the efficiency of the experiment. An upgraded K_S target station is proposed in order to reduce the accidental activity measured in the drift chambres, which is mostly due to electromagnetic showers produced in the collimator. Fig. 1 shows the layout of the K_S target station. The proton steering magnet just upstream of the target will be replaced by a stronger magnet in order to reduce the production angle of the beam. The K_S veto counter array at the exit of the K_S collimator will be dismounted, and continuous vacuum will be established along the passage of the beam. A 1.5 m long absorber plug made of bronze will be introduced into the present K_L beam aperture below the K_S beam in the final collimator. In order to reduce the charged component of the electromagnetic showers, the K_S sweeping magnet will operate at the maximum strenght, and an additional magnet will be installed downstream of the defining part of the collimator. A removable platinum absorber will convert photons downstream of

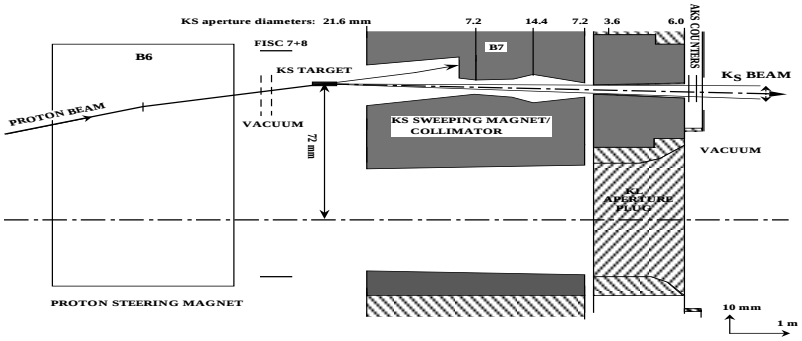

Figure 1: *Detailed layout of the* $\mathrm{K_S}$ *target station and beam (vertical section)*

the beryllium target. On the detector side, a new drift chamber readout will be installed, which will be able to handle the high intensity data flow of NA48/1 with no dead time. The optimization of the present data acquisition and trigger systems is also foreseen.

Some decay modes and parameters accessible to the NA48/1 proposal are now described.

The $\mathrm{K_S} \to \pi^0\mathrm{e}^+\mathrm{e}^-$ *decay:* this CP conserving decay is dominated by long distance dynamics through one–photon exchange. Chiral Perturbation Theory χPT predicts the branching ratio:

$$BR(\mathrm{K_S} \to \pi^0\mathrm{e}^+\mathrm{e}^-) \simeq 5.2 \times \mathrm{a_S^2} \times 10^{-9}$$

where a_S is a parameter of $O(1)$ to be determined experimentally.

The measurement of $BR(\mathrm{K_S} \to \pi^0\mathrm{e}^+\mathrm{e}^-)$ enables to bound the indirect CP violating term in the $\mathrm{K_L} \to \pi^0\mathrm{e}^+\mathrm{e}^-$ decay. There are three contributions to the $\mathrm{K_L} \to \pi^0\mathrm{e}^+\mathrm{e}^-$ decay: direct CP violating, indirect CP violating and CP conserving. The CP conserving contribution can be obtained through the study of the $\mathrm{K_L} \to \pi^0\gamma\gamma$ decay. The a_S parameter predicted by χPT describes the strength of the indirect CP violating component, which is related to $BR(\mathrm{K_S} \to \pi^0\mathrm{e}^+\mathrm{e}^-)$ with the formula:

$$BR(\mathrm{K_L} \to \pi^0\mathrm{e}^+\mathrm{e}^-) = |\epsilon|^2 \frac{\tau_\mathrm{L}}{\tau_\mathrm{S}} BR(\mathrm{K_S} \to \pi^0\mathrm{e}^+\mathrm{e}^-)$$

The present best limit on $BR(\mathrm{K_S} \to \pi^0\mathrm{e}^+\mathrm{e}^-)$ was recently published by NA48[4]. The NA48/1 proposal would yield about 7 events at $a_S = 1$, with a negligible background contamination.

The $\mathrm{K_S} \to \pi^0\pi^0\pi^0$ *decay:* CP violation in this decay can be

parametrized with the ratio $\eta_{000} = A(\mathrm{K_S} \to 3\pi^0)/\mathrm{A}(\mathrm{K_L} \to 3\pi^0)$ of $\mathrm{K_S}$ to $\mathrm{K_L}$ amplitudes. Under CPT invariance, $\mathrm{Re}(\eta_{000})$ is given by CP violation in the $\mathrm{K}^0 - \overline{\mathrm{K}}^0$ mixing, while $\mathrm{Im}(\eta_{000})$ is sensitive to direct CP violation. A better limit on η_{000} also allows an improved test of CPT based on the Bell–Steinberger unitary relation. NA48/1 aims improving the present limits on $\mathrm{Re}(\eta_{000})$ and $\mathrm{Im}(\eta_{000})$, given by CPLEAR [9] and SND [10], by measuring the $\mathrm{K_S} - \mathrm{K_L}$ interference near the production target. The NA48 data collected in the 2000 run allow to reduce the error on $\mathrm{Re}(\eta_{000})$ and $\mathrm{Im}(\eta_{000})$ at a few percent level. An ultimate error within 1% is expected after one year of NA48/1 data taking.

Neutral hyperon physics: the $\mathrm{K_S}$ target is source of neutral hyperons which decays in the NA48 fiducial volume. The intense $\mathrm{K_S}$ beam allows to improve NA48 results[6] and to start new studies.

A precise measurement of $M(\Xi^0)$ and $M(\Xi^-) - M(\Xi^0)$ has been done in NA48. NA48/1 will reduce the experimental uncertainty on $M(\Xi^-) - M(\Xi^0)$ to 0.1 MeV/c^2, which is the current error on $M(\Xi^-)$. Hyperon radiative decays have been studied in NA48 in order to investigate SU(3) simmetry breaking effects. A total uncertainty of 5% is expected in NA48/1 on the branching ratios of $\Xi^0 \to \Lambda^0\gamma$ and $\Xi^0 \to \Sigma^0\gamma$ decays. About 25k beta decays $\Xi^0 \to \Sigma^+ e^- \bar{\nu}$ should be collected in NA48/1. The present limit on the branching ratio of the suppressed $\Delta S = 2$ process $\Xi^0 \to p\pi^-$ should be improved by about two order of magnitude.

3 NA48/2: the charged kaon proposal

The high precision study of charged kaon decays offers a new important possibility to search for direct CP violation, additional to that of the neutral kaon sector without the complications induced by flavour mixing. Since no mixing is possible for $\mathrm{K}^\pm$, any difference in $K^\pm$ decay matrix elements indicates direct CP violation. The NA48 collaboration has proposed to measure a possible direct CP violating signal in the Dalitz plot decay parameter of the process $\mathrm{K}^\pm \to \pi^\pm\pi^+\pi^-$. The matrix element is parametrized as:

$$|M(u,v)|^2 \sim 1 + gu + hu^2 + kv^2$$

where: $u = (s_3 - s_0)/m_\pi^2$, $v = (s_1 - s_2)/m_\pi^2$, $s_0 = (s_1 + s_2 + s_3)/3$, $s_i = (P_K - P_i)^2$, P_K and P_i are the four momenta of the kaon and the pion (i=3 for the odd pion). If CP is conserved, then the coefficients g, h and k are the same for K^+ and K^-. A non–zero value of the asymmetry $A_g = (g^+ - g^-)/(g^+ + g^-)$ of the slope parameters g is an unequivocal signal of direct CP violation.

If the detector acceptance is independent from the kaon charge, the ratio $R(u)$ of the number of positive to negative charged kaon decays can be used as observable quantity, sensitive uniquely to Δg, and no MonteCarlo is needed to correct for acceptance.

In order to reduce differences in acceptance for the two decays, which could induce a non–zero A_g value, the experiment will use simultaneous K^+ and K^- beams, produced from the same target and overlapping in space and time. A narrow band beam is proposed with a central momentum value of 60 GeV. Major modifications to the present NA48 beam line are needed for the $K^\pm$ beam system, which could be ready to run in 2003, after the completion of the high intensity K_S physics program.

An alternate magnetic field will operate in the spectrometer in order to average any residual acceptance difference for $K^\pm$ due to detector inhomogeneities. The ratio $R(u)$ will be evaluated independently in each $K^\pm$ energy bin and averaged over different magnetic field polarities. A precision on A_g of the order of 10^{-4} is expected in NA48/2, limited only by statistics. About 10^{10} $K^\pm \to \pi^\pm\pi^+\pi^-$ decays should be collected in one year of SPS operation corresponding to a statistical accuracy of 0.7×10^{-4}. The systematic uncertainty, evaluated with a detailed MonteCarlo simulation, could be kept at the level of a few parts in 10^{-5}.

The upgrade of the NA48 detector is proposed in NA48/2. A new transition radiation detector will be used for electron/pion rejection. A new small beam spectrometer will be installed in different positions along the beam path to achieve a better measurement of momentum and position of the incident charged kaon, and constrain the kinematic reconstruction of the decays. Such a spectrometer would allow to recover useful statistics of $K^\pm \to \pi^\pm\pi^+\pi^-$

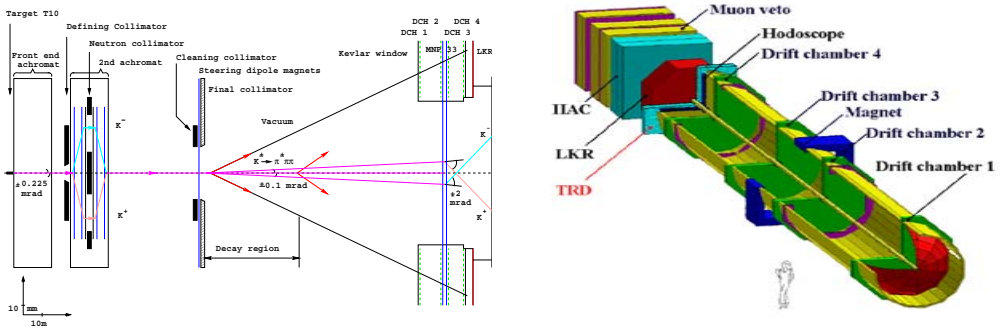

Figure 2: *Schematics layout of the NA48/2 beams and the detector.*

decays, with one undetected pion. Both these new detectors will improve the NA48 particle identification and background subtraction, and will allow NA48/2 to also study several other rare and less rare interesting $K^{\pm}$ decays. The layout of the NA48/2 beams and the detector are shown in Fig. 2.

The theoretical predictions for the A_g asymmetry in the framework of the Standard Model [11, 12] vary in the $O(10^{-6}) - O(10^{-4})$ range. In some supersymmetric models [13] A_g is expected as high as 10^{-4}. The NA48/2 proposal is about 50 times better than the present best A_g measurement [14].

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