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ADDENDUM III
(to Proposal P253/CERN/SPSC) for a Precision Measurement of Charged Kaon Decay Parameters with an Extended NA48 Setup

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1 Introduction

A high statistics study of charged kaon decays, if carried out with correspondingly high systematic accuracy, has a potential to provide important new information about direct CP-violation, additional to that obtained from the decays of neutral kaons (ϵ'/ϵ). It could also address the existence of the postulated $q\bar{q}$ condensate of the QCD vacuum, the measurement of chiral perturbation theory (ChPT) parameters and the detection of possible deviations from the V-A theory of weak interactions and from the standard model (SM).

The proposal for such a study is described in this addendum to the NA48 experimental programme. It makes use of a novel design for simultaneous K^+/K^- beams, in place of the present K_L/K_S beams, and of a transition-radiation detector (TRD) added to the NA48 apparatus.

The following three sections illustrate briefly the case for the study of direct CP violation, of K_{e4} decays and other decays of charged kaons.

All expected results are evaluated for one year of typical SPS running, which assumes $\sim$ 120 days at $\sim$ 50 % efficiency.

1.1 Direct CP-violation

New measurements of direct CP-violation in two–pion decays of neutral kaons recently published by NA48 [1] and KTEV [2] have confirmed the relatively high value of $Re(\epsilon'/\epsilon)$ first measured by NA31 at CERN [3] more than 10 years ago. The new world average value[1)] of $Re(\epsilon'/\epsilon) = (21 \pm 5) \times 10^{-4}$ is higher than the predictions of most theoretical evaluations and could be considered to be in disagreement with the Standard model (SM)[4], or at least to indicate significant problems in the calculations of non perturbative parameters of the decay matrix element[2)]. Thus a measurement of direct CP-violation in other processes is of great importance. A manifestation of direct CP-violation would be any difference between the K^+ and K^- decay matrix elements. The decays that we propose to compare accurately are $K^+ \to \pi^+\pi^-\pi^+$ relative to $K^- \to \pi^+\pi^-\pi^-$ and $K^+ \to \pi^0\pi^0\pi^+$ relative to $K^- \to \pi^0\pi^0\pi^-$. The decays $K^+ \to \pi^+\pi^0\gamma$ and $K^- \to \pi^-\pi^0\gamma$ will be studied also, but the statistics obtainable in the kinematic region most sensitive to possible CP-violation (high gamma energy in the $K^\pm$ CM system) would be more limited than for the three pion decays.

The matrix element for the decays $K^\pm \to (3\pi)^\pm$ can conveniently be parametrizied in the following form [6]:

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

where $u = (s_3 - s_0)/m_\pi^2$, $v = (s_1 - s_2)/m_\pi^2$, $s_0 = \frac{1}{3}(s_1 + s_2 + s_3)$, $s_i = (P_K - P_i)^2$, P_K and P_i are the four-momenta of the kaon and pion ($i = 3$ for the odd pion), respectively, and m_π is the mass of the charged pion. The coefficients g, h and k must be the same for the decays $K^+ \to 3(\pi)^+$ and $K^- \to 3(\pi)^-$ in case of CP conservation. As a measure of direct CP violation the asymmetry

$$A_g = (g^+ - g^-)/(g^+ + g^-)$$

is considered, where g^+ and g^- are the coefficients defined above for the K^+ and K^- decays, respectively.

In a series of theoretical papers [7] values of A_g in the range of $(2 - 4) \times 10^{-4}$ have been predicted. The value obtained in ref. [8] is 4×10^{-4}, while other authors predicted smaller values: 4×10^{-5} [9] and $(2.3 \pm 0.6) \times 10^{-6}$[10]. Calculations made in the framework of super symmetric models could give the value of the order of $\sim 10^{-4}$ [11].

The only dedicated measurement of A_g [12] performed up to now, based on about 1.6×10^6 events collected for each sign of kaon charge, has given $A_g = (-7 \pm 5) \times 10^{-3}$. The HyperCP experiment, at present running at FNAL, plans to collect 2×10^8 decays of K^- and twice as many of K^+ [13] in two years of running. It is aimed primarily at the detection of CP violation in hyperon decays and is not specifically designed for the highest possible systematic accuracy for $K^\pm$ decays.

The asymmetry parameter A_g^0 for $K^+ \to \pi^0\pi^0\pi^+$ and $K^- \to \pi^0\pi^0\pi^-$ decays has not so far been measured up in a dedicated experiment. Using the measured slopes of the Dalitz plots for K^+ and K^- decays in different experiments one could derive a value of $A_g^0 = 0.117$ within an uncertainty which is difficult to estimate [6]. Even less experimental information exists for $K^+ \to \pi^+\pi^0\gamma$ and $K^- \to \pi^+\pi^0\gamma$ decays. An asymmetry in their

1) A scale factor has been implemented for error calculation.

2) However some theoretical models could explain the measured $Re(\epsilon'/\epsilon)$ [5].

Dalitz plot parameters is expected in case of CP-violation [14].

Principle of the Experiment

Any variation in the ratio:

$$R(u) \equiv \frac{\int dv|M^+(u,v)|^2}{\int dv|M^-(u,v)|^2}, \tag{1}$$

as a function of the variable u, would show evidence of direct CP violation.

To measure $R(u)$ with minimum systematic uncertainty we plan to take data under the following conditions:

- the K^+ and K^- beams derived from the same target are present simultaneously, such that the decays of K^+ and K^- occur in the same fiducial volume;
- the field of the spectrometer magnet is frequently alternated in sign, so as to equalise the acceptances for K^+ and K^- decays even in the presence of localised imperfection in the detector;
- the data are binned in kaon momentum and the ratios (1) measured for spectrometer magnetic field orientation UP and DOWN are averaged for each kaon momentum bin. The final value obtained by averaging these ratios over all momentum bins is independent of acceptance[3)].

Expected results

More than 2×10^9 $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ and 1.2×10^8 $K^\pm \to \pi^0\pi^0\pi^\pm$ fully reconstructed decays are expected to be collected in one year of typical SPS and NA48 operation. Such statistics allows A_g to be measured with a precision better than 2.2×10^{-4}, and A_g^0 to better than 3.5×10^{-4}, including the estimated systematic uncertainties. An upper limit for the asymmetry in $K^\pm \to \pi^\pm\pi^0\gamma$ decays could be obtained at a level of 10^{-2}.

1.2 Charged K_{e4} decays ($K^\pm \to \pi^\pm\pi^\mp l^\pm\nu(\bar{\nu})$)

The hypothesis that chiral symmetry is spontaneously broken by the formation of a strong $q\bar{q}$ condensate in the QCD vacuum has not, so far, received any experimental verification. It has been shown that when the masses m_u and m_d of the two lightest quarks are set to zero, the QCD Lagrangian exhibits a chiral $SU(2)_L \otimes SU(2)_R$ symmetry, which is spontaneously broken towards its diagonal vector subgroup $SU(2)_V$ of isospin symmetry. The resulting massless pseudo-scalar Goldstone bosons are identified with the lightest isotriplet of hadronic states, the pions. In the real world of QCD with massive quarks, these Goldstone bosons receive their mass m_π. The dependence of m_π on m_u and m_d can be analysed in a systematic way within the framework of chiral perturbation theory (ChPT) [15]. It is summarised in the equation:

[3)] In practice conditions will not be ideal, but the relative insensitivity of the method with respect to imperfections makes it possible to implement the corrections (of second order) with adequate monitoring and an appropriate Monte Carlo simulation.

$$m_\pi^2 = (m_u + m_d)\langle\bar{q}q\rangle_0/F_0^2 + O(m_q^2), \tag{2}$$

where $\langle\bar{q}q\rangle_0$ denotes the single flavour condensate in the chiral limit $m_u = m_d = 0$, while F_0 stands for the value of the pion decay constant in the same limit with $F_0 \approx F_\pi = 92.4$ MeV. It is commonly accepted that the $O(m_q^2)$ corrections in expression (2) are small if the condensate is sufficiently large and therefore that the ratio

$$x_{GOR} \equiv (m_u + m_d)\langle\bar{q}q\rangle_0/(F_0^2 m_\pi^2) \tag{3}$$

is close to unity [16, 17]. This parameter governs the fraction of the pion mass due to the condensate.

The assumption of a large condensate is not a consequence of our present understanding of the non-perturbative aspects of confining gauge theories. The possibility of giving a much smaller (or even vanishing) condensate, corresponding to $x_{GOR} \ll 1$ cannot be excluded a priori. It has been shown within the framework of generalised ChPT (GChPT) [18] that low-energy $\pi\pi$ scattering in the S-wave is particularly sensitive to the size of the condensate. To lowest order, the corresponding amplitude is defined by the parameters:

$$\alpha = (4 - 3x_{GOR})[1 + O(m_q)], \tag{4}$$

and

$$\beta = 1 + O(m_q), \tag{5}$$

which are related to the S-wave scattering lengths (a_0^0 and a_0^2). The corresponding LO expressions are:

$$a_0^0 = (1/96\pi)(m_\pi^2/F_\pi^2)(5\alpha + 16\beta) \tag{6}$$

and

$$a_0^2 = (1/48\pi)(m_\pi^2/F_\pi^2)(\alpha - 4\beta). \tag{7}$$

From large condensate conditions, ($\alpha = 1 \Leftrightarrow x_{GOR} = 1$) to vanishing ones, ($\alpha = 4 \Leftrightarrow x_{GOR} = 0$), a_0^0 varies between 0.16 and 0.27. Higher-order corrections modify these numbers and at NNLO a_0^0 is found to lie between 0.20 and 0.30 [18].

The quoted parameters (3) and (6) can be determined from the measurement of $\pi^+\pi^-$ interaction at low energies, in particular, by studying the charged K_{e4} decays (K_{e4}^c). The K_{e4} decay is described in the framework of the V-A theory by a set of five variables: $s_\pi = M_{\pi\pi}^2$ and $s_l = M_{l\nu}^2$, the invariant squared masses of the di-pion and di-lepton systems, and the angles θ_π, θ_e and ϕ describing the direction of pions in the decay plane of the $\pi^+\pi^-$ system, the direction of leptons in the decay plane of the $l\nu$ system and the relative orientation of these planes, respectively.

The transition amplitude of K_{e4}^c decays given by the V-A theory can be written as a function of four form factors depending on s_π, s_l and $\cos(\theta_\pi)$. According to Pais and Treiman [19] the probability distribution can be expressed in the $\cos(\theta_l) - \phi$ plane using 9 coefficients, from which the form factors can be extracted. One can write the $\cos(\theta_\pi)$ dependence of the form factors explicitly by making a partial wave expansion of the hadronic current (form factors) with respect to the momentum of the di-pion system. Because of the small value of s_π, these expansions may be restricted to s and p waves. It has been shown within ChPT [20] that the corrections to the Pais-Treiman formula due to higher partial waves are small. Under the assumption of T invariance the Fermi-Watson theorem implies that the phases in the partial wave expansions are the phase shifts of the elastic $\pi\pi$ scattering. Assuming that the $\Delta I = 1/2$ rule suppresses the $(l = 0, I = 2)$ partial wave, the analysis of the decays leads to the knowledge of 3 real form factors and to $\delta = \delta_0^0 - \delta_1^1$, the phase shift which can be evaluated as a function of s_π:

$$\sin 2\delta = 2(\frac{s_\pi - 4m_\pi^2}{s_\pi})^{1/2}(a_0^0 + bq^2/m_\pi^2), \tag{8}$$

where $b = b_0^0 - a_1^1$, i.e., the difference between the s-wave slope and the p-wave scattering length.

A GChPT fit to the experimental K_{e4} data [21] gives:

$$\alpha = 2.16 \pm 0.86, \quad \beta = 1.074 \pm 0.053.$$

This leads, at NNLO, to the present value of a_0^0:

$$a_0^0 = 0.263 \pm 0.052.$$

The quoted errors are dominated by the experimental uncertainties on the low-energy phase shift difference extracted from the K_{e4} data. It is clear that a more precise measurement of these low-energy phase shifts in a new K_{e4} experiment with high statistics would provide an accurate determination of α and β. Since the large condensate assumption underlying SChPT can hardly accommodate values of α that deviate strongly from unity [23], this new measurement will be a crucial test for the theory. An earlier experiment (30000 K_{e4} with 1% background) [21] did not collect enough statistics to give unambiguous support to the strong condensate hypothesis. A new experiment at Brookhaven [22] accumulated more than tenfold statistics (437000 K_{e4} with 2% background) compared with the earlier one. But even the precision of the Brookhaven result is limited by the accumulated statistics.

Expected results

More than 10^6 K_{e4}^c charged kaon decays are expecting to be recorded in one year of running of the proposed NA48 setup. These should allow a_0^0 to be measured with an accuracy of 0.01 and the precision of the phase shift δ measurement to be improved. These data will be complementary to the ones already existing elsewhere in terms of different systematic uncertainties and would allow the size of the QCD condensate to be established.

1.3 Other decays

Other decays of charged kaons which could be precisely measured in the experiment are presented in Table 1. The relevant measurements allow the ChPT parameters to be estimated and some check of the V – A theory to be performed.

The radiative decays $K^\pm \to \pi^\pm\gamma\gamma$, $K^\pm \to \pi^\pm\gamma\gamma\gamma$ and $K^\pm \to \pi^\pm\pi^0\gamma$ are sensitive to the non-perturbative contributions of the strong interactions and thus cannot be calculated in the Standard Model. A term of order $O(p^4)$ essentially contributes to the decays $K^\pm \to \pi^\pm\gamma\gamma$ in the ChPT calculations and consequently the corresponding decay width is directly related to the scale independent coupling constant $\hat{c}$ according to [24]:

$$Br(K^+ \to \pi^+\gamma\gamma) = (5.26 + 1.64\hat{c} + 0.32\hat{c}^2 + 0.49) \times 10^{-7}$$

A precise estimation of this constant could be obtained in the measurement of the $K^\pm \to \pi^\pm\gamma\gamma$ branching ratio.

Table 1: $K^\pm$ decays

Decay	Experimental Br, [6]	Expected events in NA48	Measured parameters
$K^+ \to \pi^+\gamma\gamma$	$(1.10 \pm 0.32) \times 10^{-6}$	$10^3 - 10^4$	ChPT ($\hat{c}$)
$K^+ \to \pi^+\gamma\gamma\gamma$	$\leq 10^{-4}$	$\leq 0.2 \times 10^6$	Br
$K^\pm \to \pi^\pm\pi^0\gamma$	$(1.8 \pm 0.4) \times 10^{-5}$	$10^4 - 10^5$	A'_g, ChPT
$K^\pm \to \pi^0 l^\pm \nu$	8%	$> 2 \times 10^8$	f_v, f_t, f_s

The sensitivity of the experiment would allow us to improve the upper limit of the branching ratio $K^+ \to \pi^+\gamma\gamma\gamma$ by more than two orders of magnitude.

In addition to the measurement of CP-violating asymmetry in $K^\pm \to \pi^\pm\pi^0\gamma$ decays, the contribution of the chiral anomaly to the decay amplitude could be estimated. This anomaly corresponds to the $O(p^4)$ term, which is dominant since the bremsstrahlung and one-loop amplitudes are very small [27].

The latest measurements of the charged K_{e3} decays, $K^\pm \to \pi^0 e^\pm \nu(\bar{\nu})$, give significant values of the scalar (f_s) and tensor (f_t) form factors which indicate a deviation from the V-A theory [25]. Thus, the precision measurement of these form factors (f_t, f_s) is necessary to check the V-A theory. The corresponding measurements in the proposed experiment are expected to be at least 3 times more precise than in [25].

2 Simultaneous K^+ and K^- Beams

In order to compare the decays of K^+ and K^- with minimum systematic bias, it is proposed to rebuild the K12 beam downstream of the present K_L target (T10), so as to transport simultaneously positively and negatively charged particles of the same momentum. These should be selected with the same geometrical acceptance and be directed along a common line pointing towards the NA48 detectors. To accommodate the required features, the K_S beam elements of the present layout must be removed. The installation of the new beam line therefore follows the termination of the high intensity K_S programme and might be planned for the following SPS shut-down.

The beams of charged particles are derived from primary protons from the SPS transported via the P42 beam line onto the present target station T10. This incorporates a 2 mm diameter, 400 mm long beryllium target followed by a water cooled, copper collimator of 15 mm aperture to absorb large-angle secondary particles. The angle of incidence of the protons onto the target can be varied between 0 and -2.5 mrad. The central momentum and momentum bite are then selected symmetrically for positively and negatively charged particles by their passage through two vertical deflection magnets with opposite-sign field and a pair of dump/collimators (TAX), which have variable but similar openings (momentum slits) for each of the two beams and also serve to absorb the remaining primary

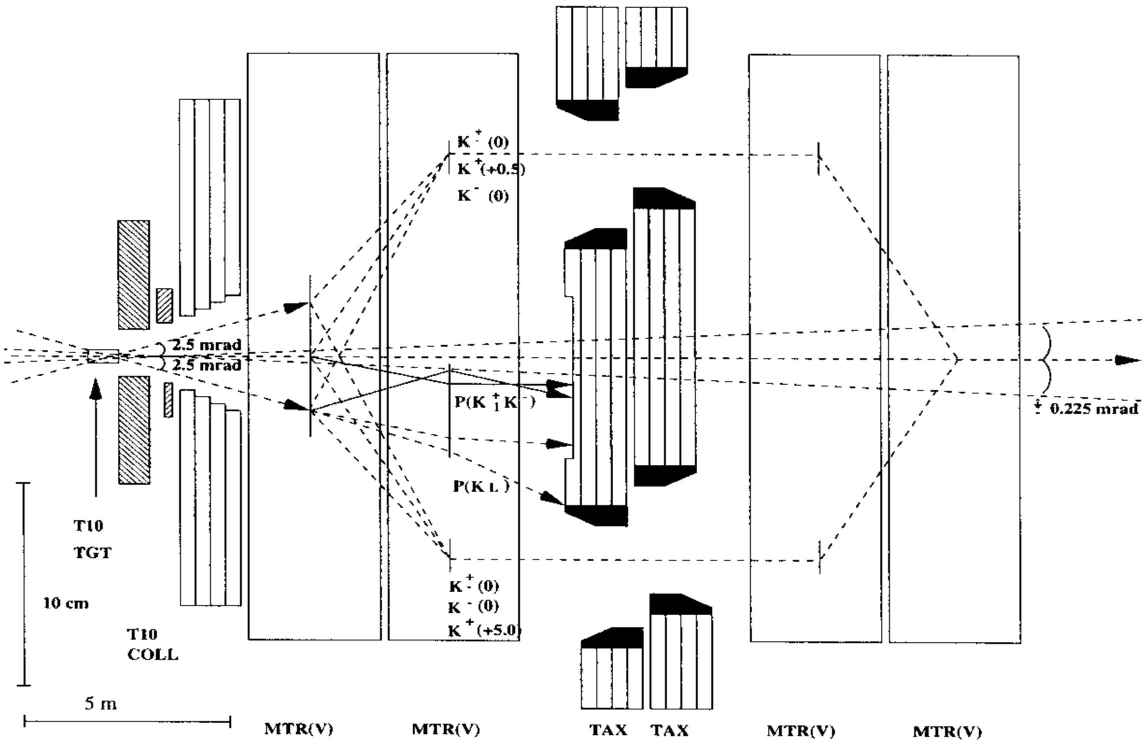

Figure 1: Schematic layout of front end of simultaneous K^+ and K^- beams.

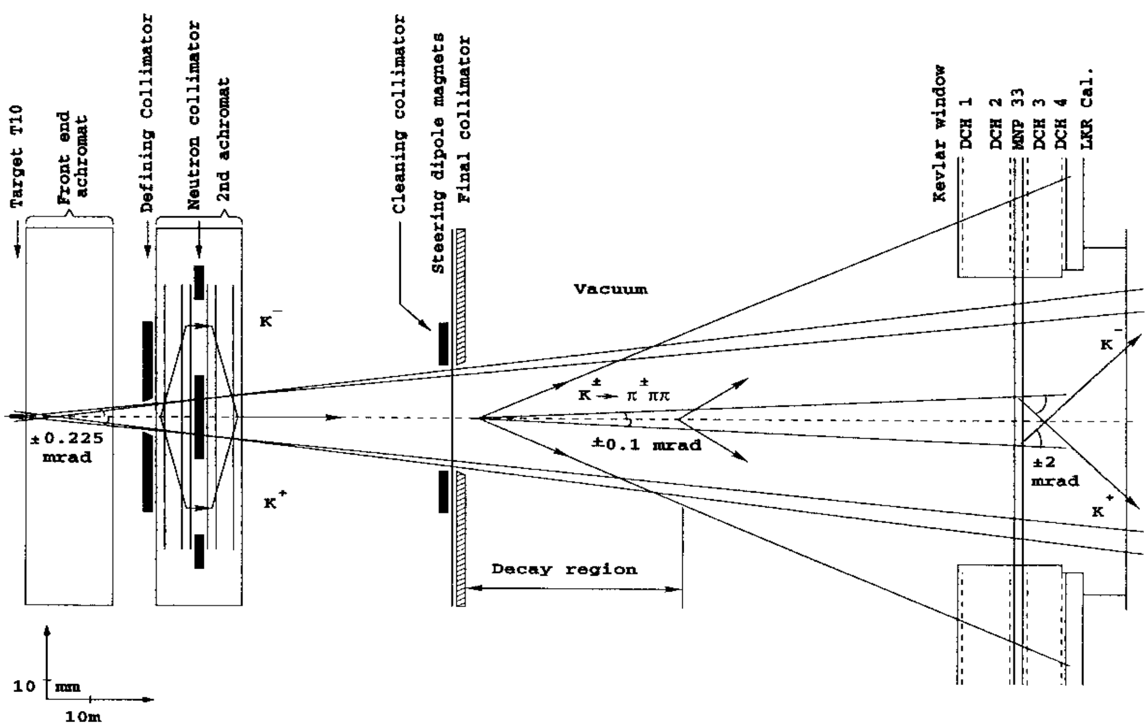

Figure 2: Schematic layout of K^+ and K^- beams

protons. Following these dump/collimators, two further vertical deflection magnets return the two beams onto a common axis. The design of this momentum-analysing and -recombining front end or "beam achromat" is shown schematically in fig.1.

For the purpose of studying systematic effects, the combination of magnet settings and positions of the TAX apertures permit the paths of the positively- and negatively-charged beams to be inversed or one or other of the beams to be selected on its own. Moreover it is possible to incorporate into the design an option for a K_L beam which could operate alternately to the charged kaons.

The layout of the complete beam line following the momentum-selecting achromat is shown schematically in fig.2. The two beams are defined to be collinear, with an angular acceptance from the target of ± 0.225 mrad in each plane, by a collimator placed ~ 32 m from the target followed by a second achromat composed of 4 dipole magnets, again separating and recombining the two beams and incorporating a 'neutron collimator'. This collimator has openings for each of the charged beams and serves to block the passage all neutral- and many charged-particles produced on the defining collimator. The second achromat may also serve as a beam spectrometer, accommodating position sensitive detectors to determine the momentum of individual particles within the momentum bite of the beam[4]. At the centre of the achromat the two beams are separated by $\sim 80mm$, with a position dependence on momentum of $\sim 0.4mm/\%\Delta p/p$ within lateral spot-sizes of $\sim 20mm \times 30mm$ (for $\Delta p/p = \pm 10\%$).

The detectors of the experiment are further protected against background around the beams by a cleaning collimator at ~ 110 m and a final collimator ending at 114 m from the target. Just upstream of the last collimator, small steering dipole magnets allow the two charged beams to be perfectly aligned in both planes as they enter the decay region pointing towards the detectors. Alternatively, the horizontal dipole could be used to disperse the beams by small angles of about ∓ 0.1 mrad. The aim would be to balance the left/right excursions in the passage through the first drift chamber with those in the fourth due to deflections of about∓ 2 mrad in the spectrometer magnet of the experiment (as shown in fig.2).

The principal parameters and expected performance of the proposed simultaneous K^+ and K^- beams, as they might be provided after the completion of the high intensity K_s program, are listed in Table 2. The sensitivity and counting rates for the new beam are quoted for 10^{12} protons per pulse incident on the target, benefiting, from the introduction of the 400 GeV/c, long duty-cycle SPS cycle, requested for the intense K_S beam. The fluxes of negatively- and positively-charged hadrons transported by the beam as a function of momentum are plotted in fig.3 with zero production angle[5]. The corresponding fluxes of $K^\pm$ and $\pi^\pm$ decaying in the fiducial region are plotted in fig.4. As an example, a central momentum of 60 GeV/c and a momentum bite of $\pm 10\%$ (shown in fig.5) are chosen. With these conditions, the instantaneous counting rates in the principal detectors are estimated to be comparable to those currently observed from the simultaneous $K_L + K_S$ beams.

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[4] A possibility to use MICROMEGAS as a position sensitive detector is under study.

[5] Alternatively, the two beams can be accepted at angles of ± 2.5 mrad with respect to the target. If then the primary protons are incident at -2.5 mrad, the production angles of the negative and positive beams can be 0 and 5 mrad, respectively, thereby reducing the difference in flux between the two beams.

Table 2: Parameters of the simultaneous K^+/K^- beams

Beam	K^+	K^-
Proton momentum, GeV/c	400	
Duty cycle, s/s	5.0 / 19.2	
Protons per pulse on target	1×10^{12}	
Production angle, mrad	0.0	
Length: Target - Final coll., m	102	
Distance: Final coll. - LKr, m	139	
Beam acceptance angle, mrad	± 0.225	
Beam acceptance solid angle, ster	$5.06\pi \times 10^{-8}$	
Central momentum, in GeV/c	60	
Momentum range: $\Delta p/p$, %	± 10	
Beam flux, protons /cycle, in 10^6	7.5	–
Beam flux, π per cycle, in 10^6	29.0	17.3
Beam flux, K per cycle, in 10^6	1.9	1.1
Kaon decays in 50 m per year (1/2 × 120 days), in 10^{10}	5.5	3.1

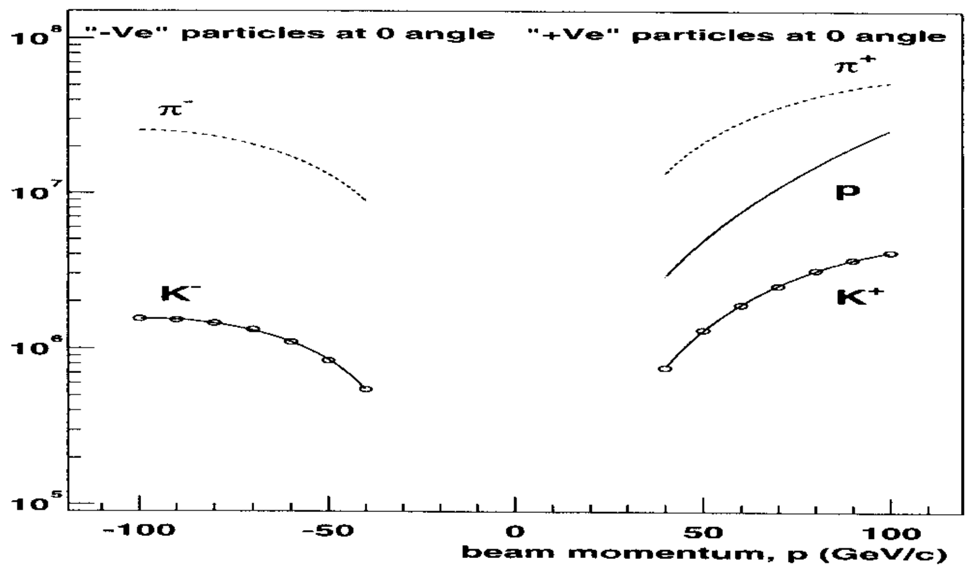

Figure 3: Beam flux in $\Delta p/p \pm 10\%$ at exit of final collimator per 10^{12} ppp (400 GeV/c) on target T10.

Installation and costs

The installation of the proposed beams entails the removal of the K_S beam option and the rebuilding of $\sim$ 120 m of the K12 beam line leading from the target station T10 towards the decay volume and detectors of NA48. In addition to the target station it is possible to keep the beam dump/collimator (TAX) mechanisms at their present locations and to make use of existing magnets and other beam elements. The project requires

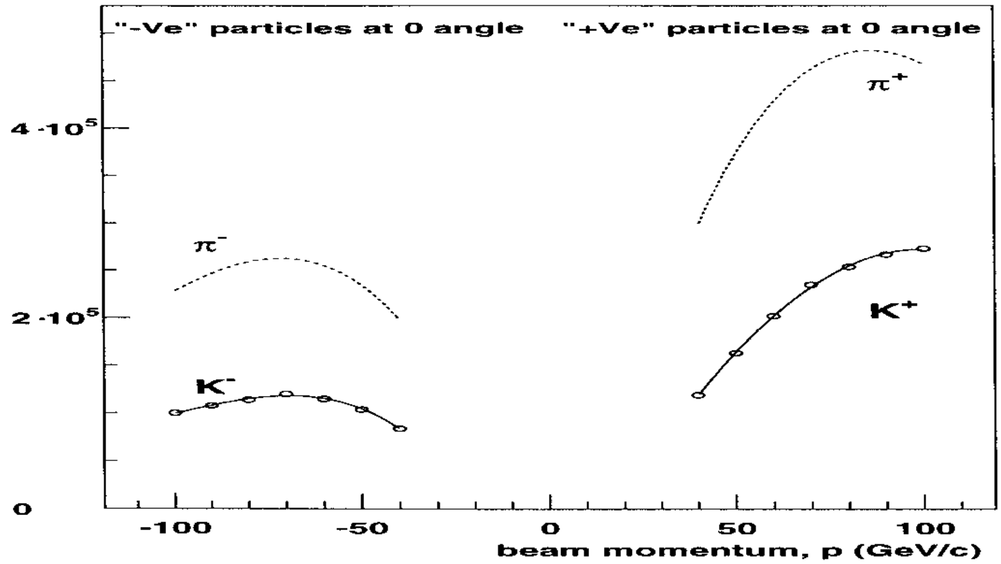

Figure 4: Flux of particles decaying in 50 m fiducial length per 10^{12} ppp (400 GeV/c) on target T10.

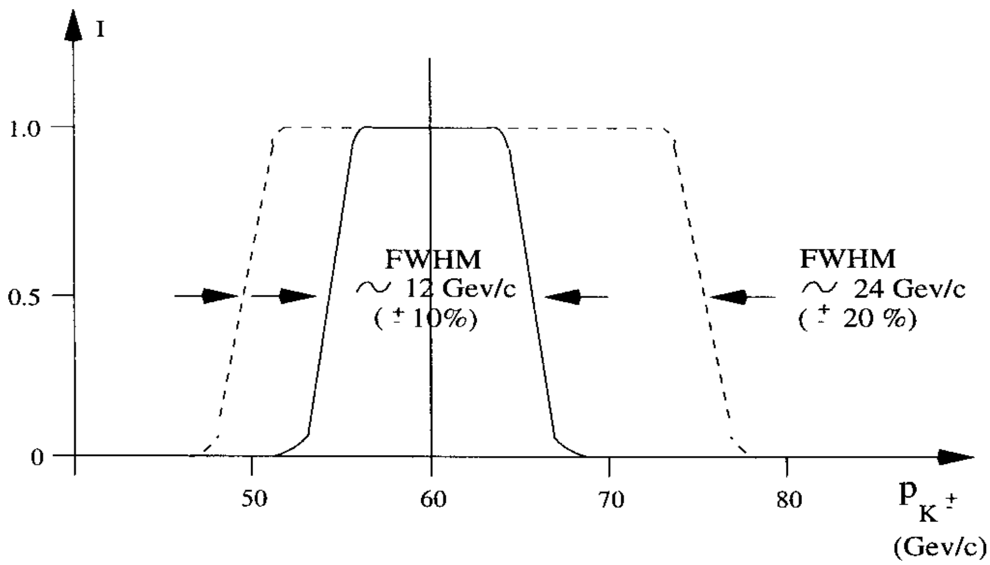

Figure 5: Momentum distribution of beam particles at exit of final collimator

new, machined copper and iron blocks for the TAX and tungsten-alloy inserts for the various collimators as well as special support for magnets and adaptation of the neutron collimator. Otherwise, it entails contractual work of re-deploying the power, cooling and control connections from the adjacent technical gallery to the new beam elements and instrumentation.

The optimum decay fiducial region for the K^+ and K^- is displaced upstream with respect to the present decay region for K_S and K_L. We therefore propose to displace the final collimator so as to end at 102 m from the target (as indicated in Table 2) and to add $2 \times 12m$-long sections (recovered from experiment NA31) to the upstream end of the 1.92 m diameter, cylindrical steel vacuum tank now installed.

We also note that, at present, the Kevlar exit-window to the vacuum tank, as well as the four drift chambers of the spectrometer together with their adjoining beam vacuum tube, are aligned along the bisector of the converging K_L and K_S beam lines. In order to symmetrise the beam aperture and acceptance of the detectors around the common K^+/K^- beam axis, which coincides with that of the present K_L line, we propose to realign these elements onto this line.

The proposed transformation can be accomplished with a minimum of additional manpower and without loss of beam time if it is planned for an appropriate annual shut-down of the SPS. Under these conditions it is estimated to cost CHF140k.

3 Detectors

The major elements of the NA48 detector are the magnetic spectrometer, liquid krypton electro-magnetic calorimeter, hadron calorimeter, muon veto and hodoscope of scintillator counters, which could be used without any modifications. The only additional detector is the transition radiation detector (TRD), which is needed to separate electrons/positrons from hadrons for the reliable identification of K^c_{e4} and some other decays.

3.1 Magnetic spectrometer

The value of the magnetic field in the spectrometer is chosen to optimise the acceptance of the detector. For the proposed beam momentum of 60 GeV/c the integral of the magnetic field is limited to provide 120 MeV/c of transverse momentum kick. The magnet polarity will be regularly alternated.

3.2 Transition radiation detector (TRD)

The required pion rejection power for electron identification from the TRD has to be larger than 100 at 90% electron detection efficiency in a momentum range from 1 to 50 GeV/c.

It is proposed to use as a TRD seven modules of a large area NOMAD TRD [26] with some modifications. The NOMAD TRD identifies electrons at 90% efficiency with a rejection factor against pions of 10^3 over an area of $2.85 \times 2.85 m^2$. It consists of nine modules, each of which includes a 315 plastic foil radiator and a detector plane of 176 vertical straw tubes with xenon-methane gas mixture.

The mechanical construction of the NOMAD TRD allows seven modules to be separated and adjusted to the NA48 Set-Up. These modules will be combined with the existing NA48 scintillator hodoscope in a single structure to be placed in the space between the magnetic spectrometer and the liquid krypton electro-magnetic calorimeter. The major modification of the NOMAD TRD is related to the necessity for the beam of having a central hole through which a vacuum tube of diameter $\sim 20cm$ passes. A test of cutting such a hole in the prototype of the NOMAD TRD radiator has been successfully carried out. The straws located above and bellow this hole can be prepared by shortening the existing straws or preparing new ones. The free straw ends have to be connected to the gas system and are fixed to a thin kapton frame. The area with additional material around the hole is not larger than 36 cm in the vertically and 26 cm in horizontally.

To obtain the characteristics of the proposed TRD a Monte Carlo simulation has been made. For the electron identification the NOMAD algorithm was used. The TRD hits collected along the road of a DCH track are assigned to the track. The energy depositions in the associated hits are then compared to these expected for the two-particle hypothesis, electron and pion, taking into account the momentum of each particle, as measured by the magnetic spectrometer.

For each track with associated TRD hits a likelihood ratio estimator L is calculated:

$$L \sum_{i=1}^{Nhits} \log \frac{P(E_i|e)}{P(E_i|\pi)},$$

where N_{hits} is the number of TRD hits associated with a track, $P(E_i|e)$ and $P(E_i|\pi)$ are the probability density functions for the electron and pion to deposit the energy E_i in the i-th straw tube. These functions have been obtained from the Monte Carlo simulation.

Choosing the appropriate threshold for L we can distinguish electrons from pions with a large factor for pion rejection at an electron detection efficiency $\epsilon_e \approx 90\%$.

As an example, the pion rejection factors have been calculated for the decay $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$, shown in table 3. This decay forms the main expected contribution to the background for the rare decay K^c_{e4}.

Table 3: Pion rejection factors

Number of TRD module	Number of Straw	π rejection factor	
		at $\epsilon_e = 0.9$	at $\epsilon_e = 0.95$
7	1260	345	111

The proposed TRD has characteristics satisfying the required conditions for the selection of charged kaon rare decays.

Front-end and read-out electronics

The underlying assumption for the readout design is that TDR data is routed with the data of the rest of the spectrometer to the Data Merger, and from this fed to the third level trigger processor to produce the required rejection of background event.

The TRD proportional tubes signals will be processed by fast current amplifiers/shapers with tail cancellation. A possible choice for the wire amplifier could be the Upenn ASD8 chip (its analog monitor outputs could be used in our application).

The amplifier-shaper module will be developed on the base of a chip ASD-8, having an input impedance of 125 Ω at the frequency up to 30 MHz, a linear dynamic range of 50 fC and a response of 2.6 mV/fC.

The wire current signals will be processed by Front-End Digitizers (FED) similar to the analog Pipelined Memory Boards (PMB) developed by INFN Cagliari for the hodoscope and veto readout.

The Front-End module will digitize the input signal at 40 MHz rate with 10 bit resolution. Such resolution is chosen to maintain the format of the output data from the TRD FED similar to that used by the hodoscope readout and thus achieve the same datapath bandwdth. Higher resolution (up to 12 bit) is achievable as well with less efficient data formating. Estimating in 250 ns the drift time in the TRD tubes it is foreseen that each TRD FED must produce 10 + 2 + 2 samples per channel per event (16 is the maximum allowed).

The TRD FED will be built as 24 inputs, single width, 9U VME modules: with 16 modules in a VME crate, the whole readout system will require a rack of 4 VME for a total of 1536 channels (almost 20% spare channels included).

A Data Routing Module (DRM) in each crate will distribute the Clock and the Trigger Supervisor signals to each TRD FED as well as collect the TRD data generated from the FEDs in response to the Trigger Supervisor request.

The four DRM modules will be supervised by a Read-Out Controller (ROC) module, which will be placed in a dedicated crate together with:

- a Trigger Interface (TIC) module providing the Trigger Supervisor signal to the ROC;
- commercial RIO boards providing the link to a machine in the DAQ PC arm.

The DRM and the ROC modules will possibly be the exact reproduction of those developed by INFN Cagliari, in order to minimise both the hardware and the system integration development time.

4 Triggers

The major trigger logics is based on the output signals that are already available in the NA48 experiment. The expected rates at various trigger elements have been estimated in special test runs (# 8826-8830) at fluxes rates which are close to the ones of the proposed experiment. The decay rates between the final collimator and the charged hodoscope are shown in table 4. Expected rates in different detectors are significantly lower, because the main part of decay products goes through the beam pipe.

Table 4: Decay rates (between the final collimator and charged hodoscope)

	Test	Proposed $K^{\pm}$ beams
Primary proton momentum	450 GeV	400 GeV
Duty cycle, s	2.5/14.4	5/19.2
Production angle, mrad	-1.6	0
Beam acceptance solid angle, 10^{-8} sret	2.25π	5.06π
Momentum, Gev/c	60	
Momentum bite	±23%	±10%
Decays	Rates, kHz	
$\pi^{+} \to \mu\nu$	240	240
$\pi^{-} \to \mu\nu$	150	140
$K^{+} \to All$	110	110
$K^{-} \to All$	70	60

In addition there is a muon background at the level of 450kHz, arising primary the initial proton beam targeting and dumping, which is expected to be improved in the proposed new beam design.

4.1 Trigger for the decays $K^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{\mp}$ and K^{c}_{e4}

The trigger rates due to the $K^{\pm}$ and $\pi^{\pm}$ decays and muons caused by targeting and dumping the primary proton beam are presented in Table 5. These rates have been obtained in the detailed Monte-Carlo simulation of the real experimental conditions using as a reference the rates obtained in the test runs.

Table 5: Rates at various trigger elements

Logic	Rates, kHz		Trigger Efficiency, %	
	$K^{\pm}, \pi^{\pm}$ decays	μ background	$K_{3\pi}$	K^{c}_{e4}
$QH \cdot QV$	567	417	–	–
QX	139	18	98.2	91
$Q2$	126	16	99.7	–
$DCH1 > 3$	47	–	97.6	–
$Q2\&DCH1 > 3$	37	–	97.1	–
$QX\&\overline{1\mu}$	88	6	–	–

The trigger for the decays with predominately charged particles (and/or neutrinos) in the final state will be made at different levels according to the following scheme:

Level 0
A coincidence of hits in the opposite quadrants of the hodoscope (QX condition) will be required as a pre-trigger condition both for $K_{3\pi}$ and K^{c}_{e4} decays.

Level 1
The absence of signals in the muon detector (MUV) $TR1 = QX\&\overline{1\mu}$ will be required.

The expected rate of TR1 is less than 100 kHz.

Level 2
The TR1 rate is acceptable for the MASSBOX, which will be modified to select events with 3 charged tracks. The simpler possible MASSBOX trigger requirement is:

- At least 2 vertices in the fiducial region coincident in space within the expected resolution.

The expected output rate of the MASSBOX is less than 5 kHz.

Level 3
The following parameters should be reconstructed off-line and relevant selection criteria applied:

- Closest distance of approach (CDA) of the tracks;
- Ratio of the energy deposited in the calorimeter to the momentum for each track (E/p);

- Longitudinal and transverse decay vertex positions and their extrapolation through the detector;
- Total kaon momentum;
- Transverse momentum of the reconstructed kaon relative to the direction defined by the line pointing the target at the decay vertex;
- Simplified particle identification by the TRD;
- Invariant kaon mass ($K_{3\pi}$ case);
- Values of u and v ($K_{3\pi}$ case).

The *Level 3* output gives different streams of data according to the trigger type. If needed, it could reduce significantly the amount of data recorded.

4.2 Trigger for the decays $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$, $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ and $K^{\pm} \to \pi^{\pm}3\gamma$

The trigger for the decays with gammas in the final state will be based on the existing NA48 neutral trigger logic. The trigger requirement is more than 3 peaks in at least one projection. Such a requirement reduces the rates in the detectors to an admissible level, but introduces additional inefficiencies of about 5% for $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decay. A minimum bias trigger with a lower limit on E_{tot} is proposed for $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ and $K^{\pm} \to \pi^{\pm}3\gamma$ decays.

4.3 Triggers for other decays

Trigger for the decay $K^{\pm} \to \pi^{\pm}2\gamma$

Since this decay channel is not distinguishable from the decay $K^{\pm} \to \pi^{\pm}\pi^{0}$ at the level of the neutral trigger, a new trigger has to be developed, where the information from the neutral trigger is combined with the information from the MASSBOX and HAC in order to calculate $M_{\gamma\gamma}$, the effective mass of two photons. A loose cut on the $M_{\gamma\gamma}$ mass could reduce trigger rates significantly.

Trigger for the decay $K^{\pm} \to \pi^{0}e^{\pm}\nu_{e}$

A neutral trigger condition for exactly 3 peaks in each projection, appropriately downscaled, will be used.

Trigger for the decay $K^{\pm} \to \pi^{0}\mu^{\pm}\nu_{\mu}$

A possible trigger condition for at least 2 peaks in the NUT combined with a requirement for one hit in MUV could efficiently select this decay channel.

5 Measurement of CP-Violation Asymmetry

5.1 $K^{\pm} \to (3\pi)^{\pm}$ decays

The decays $K^{+} \to \pi^{+}\pi^{+}\pi^{-}$ and $K^{-} \to \pi^{-}\pi^{-}\pi^{+}$ are the most promising ones among the processes available for the search for direct CP-violation.

The Monte Carlo simulation has shown that optimal acceptance and good resolution are obtained at the kaon beam momentum of 60 GeV/c. Other estimated conditions for reconstruction of $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ and $K^\pm \to \pi^\pm\pi^0\pi^0$ decays are presented in Table 6.

The statistical error of A_g for $N^\pm$ reconstructed $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ events is estimated as $3.7 \times \sqrt{1/N^+ + 1/N^-}$ under the conditions considered. The statistical error of the corresponding asymmetry A_g^0 for $K^\pm \to \pi^\pm\pi^0\pi^0$ decays is estimated as $1.7 \times \sqrt{1/N^+ + 1/N^-}$. Taking into account the beam parameters and calculated acceptances (see Tables 2 and 6) one year of typical SPS running is required to achieve the statistical precision of 1.7×10^{-4} and 3.1×10^{-4} for the measurements of A_g and A_g^0 respectively.

Table 6: Conditions for reconstruction of $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ and $K^\pm \to \pi^\pm\pi^0\pi^0$ decays.

Decay	$K^\pm \to \pi^\pm\pi^\pm\pi^\mp$	$K^\pm \to \pi^\pm\pi^0\pi^0$
Acceptance, %	32.0	6.5
K^+/K^- reconstructed decays/pulse	4800 / 2900	300/180
K^+/K^- reconstructed decays/year	$(1.30/0.75) \times 10^9$	$(8.2/4.7) \times 10^7$
Kaon mass resolution , MeV/c2	1.6	1.2
Kaon momentum resolution, MeV/c	0.46	0.36
Z vertex resolution, cm	65.0	62.2
Resolution on u	3.3×10^{-2}	1.9×10^{-2}

Background

There is no significant background neither for $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ nor for $K^\pm \to \pi^\pm\pi^0\pi^0$ decay reconstruction.

The possible sources of background for $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ decay reconstruction are:

$$K^\pm \to \pi^\pm \; \pi^\pm \; \pi^\mp, \quad \pi^\mp \hookrightarrow \mu^\mp\nu \tag{9}$$

which has an initial rate[6] of 21% and after applying the relevant selection contributes to the final sample at the level of 0.004%,

$$\textit{and} \qquad K^\pm \to \pi^\pm \; \pi^0, \quad \pi^0 \hookrightarrow ee\gamma \tag{10}$$

which has an initial rate of 4.5% contributing less than 0.0002% to the final sample.

The background sources considered give no significant contribution to the estimation of Ag.

Systematics

The following major error sources have been studied for the measurement of A_g and their effects evaluated in the Monte Carlo simulation:

[6] The rate is calculated with respect to the initial number of $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ decays

- The magnetic field in the decay region (Earth's field and remnant field in the vacuum tank);
- Difference in the K^+ and K^- beam momentum spectra and the angular difference between their beam axes ($\Delta\Theta$);
- Track-charge misidentification at the reconstruction stage;
- Accidentals from $K^\pm$ and $\pi^\pm$ decays;
- Resolution effects.
- Difference in hadronic interaction between positive and negative pions in the material of the spectrometer.

A 1.1 MHz overall accidental rate is expected from decaying kaons and pions, and from muons produced by targeting and dumping of initial protons. The different rates of the accidentals caused by μ^+ and μ^- in MUV (mainly from π^+ and π^- decays) have no effect on the K^+ and K^- acceptance difference because all such events are rejected if the muons are in time coincidence with the $K_{3\pi}$ decays.

The MC analysis shows that any other asymmetry arising from the different rates of positively and negatively charged accidentals could not generate a systematic error in the A_g measurement larger than 0.8×10^{-4}.

The estimations of the systematic effects are given in Table 7. The expected value of the total systematic error does not exceed 1.4×10^{-4}.

Table 7: Corrections and systematic uncertainties on A_g.

Source	Correction	Uncertainty
Beam non-collinearity	$25 rad^{-1} \times \Delta\theta$	$\pm 1.0 \times 10^{-4}$
Beam momentum binning	–	$\pm 1.0 \times 10^{-4}$
Accidentals	0.1×10^{-4}	$\pm 0.2 \times 10^{-4}$
Magnetic field in the decay region	$10^{-2} \times A_g$	$\pm 2.0 \times 10^{-6}$
Charge misidentification	-1.8×10^{-4}	–
Resolution on u	$10^{-2} \times A_g$	–

The study of possible systematic errors for the measurement of A_g^0 indicates that they are even smaller than those for A_g.

Summary

Expected precision of 2.2×10^{-4} in the measurement of the CP-violating parameter A_g could by achieved in one year of typical SPS running with the proposed simultaneous K^+ and K^- beams and existing NA48. The corresponding precision in the A_g^0 measurement is 3.5×10^{-4}.

5.2 $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ decays

The radiative nonleptonic decay mode $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ suffers from a significant background among the reconstructed events due to its small branching ratio 2.75×10^{-4}. The major background contribution comes from the $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays with one missing photon. The MC simulation gives a signal to background ratio at the level of $\sim 1 : 5$. The calculated acceptance is $\sim 11\%$ which leads to $\sim 10^{6}$ reconstructed $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ decays in one year of SPS running.

This would allow a statistical error in the measurement of the slope asymmetry A' at the level of few per cent to be achieved. The systematic error is expecting to be significantly lower.

6 Measurement of K^{c}_{e4} Decays

The analysis of K^{c}_{e4} decays is complicated by the fact that the kaon momentum is not measured explicitly. The same momentum spread $\Delta p/p$ applies to K^{+} and K^{-} given by the positions and apertures of collimators in the magnetic beam line. The momenta of the three charged particles are measured by the spectrometer, whereas only the line of flight of the kaon is known. This leads to 0C fit of the K_{e4} decay with two solutions p_1 and p_2 for the kaon momentum. When both these solutions are within the momentum spread Δp of the beam the choice is either to reject this type of event or to use the average value $p_0 = (p_1 + p_2)/2$. In this later case the resolution of the measured quantities become worse. Table 8 shows the resolution on all five kinematic variables for each strategy, compared with the resolution of experiment [21] where the kaon momentum was measured with $\pm 2\%$ accuracy.

Table 8: Resolutions on the measurable parameters and acceptance of K^{c}_{e4} decays

	Published Result [21]	P_K closest	$P_K = 60 \pm 6$, GeV/c	
$M_{\pi\pi}$ (MeV/c2)	2.5	1.5	1.5	1.5
$M_{e\nu}$ (MeV/c2)	6.3	5.1	7.7	8.7
$\theta_{\pi\pi}$ (rad)	0.05	0.037	0.05	0.066
$\theta_{e\nu}$ (rad)	0.06	0.047	0.06	0.074
ϕ (deg)	9.0	9.5	12	16
Acceptance		36%	29%	35%
Comment	$\Delta P/P = 2\%$		A	B

In strategy A a cut is made at $|p_1 - p_2|/p_0 < 2\%$, while in strategy B the averaged solution is used instead.

The choice of strategy (A) would correspond to the best resolution on the Cabbibo-Maksymovicz variables. With the assumption that the cuts in the final analysis will cause a loss in statistics of $\sim 30\%$, we expect the following yield from Monte-Carlo (MC) simulation: 7×10^{5} events/year corresponding to $\sim 9 \times 10^{10}$ $K^{\pm}$ decays/year.

MICROMEGAS

A strategy C could be considered in the case of implementing a beam spectrometer. The problem of double solution doesn't hold anymore if the beam momentum can be measured with sufficient accuracy. This can be done downstream of the first achromat system selecting the momentum range by measuring the change of the particle direction in the bending plane of the second achromat (see Section 2). The requirements are demanding because of high beam rate conditions of $\sim 10^7$ particles/s and because only minimum amount of material is acceptable in the beam in order to avoid parasitic interactions and multiple scattering which increases the beam divergence and degrade somewhat the quality of collimation. Conventional detectors like MWPC's or scintillating fibers cannot be used and are not suited for this purpose. We intend to use the MICROMEGAS device which is a new generation of gas type chamber based on very fast ion collection produced during the amplification process. This reduces space charge effect and offers rate capabilities of up to 10^6 particles/$(s \cdot mm^2)$. Using such detectors as projection chambers allows to minimise multiple scattering of the beam that will cross only the windows confining the gas volume. Each spatial co-ordinate is obtained from the measurement of the arrival times t_1 and t_2 of electrons drifting in opposite directions of two adjacent chambers with $t_1 + t_2 = const.$ A 1 ns time resolution is necessary to solve ambiguities associated with the high intensity of the beam. Tests on these detectors are going on and up to now they are very promising. Four sets of two chambers are necessary for our application and it represents about 800 channels. A momentum resolution of $< 1\%$ can easily be achieved and therefore a significant gain is expected. It will also be very useful for all decays with only one charge particle in the final state.

Backgrounds and systematic errors

Previous analyses have shown that systematic error on form factors and phase shifts are mainly due to background channels [21]. The K^c_{e4} trigger conditions will be satisfied by $K^\pm$ decays producing three charged tracks among which one is $e^+(e^-)$ or a pion fulfilling the E/p condition or producing an energetic delta ray. A study with MC has been made for the channels $K^+ \to \pi^0 + X+$ with a Dalitz decay of the π^0. These decays are rejected with the following kinematic cuts: $|\theta_{ee}| > 1$ mrad, $M_{ee} > 20$ MeV/c^2 and only one charged track with $E_{cal}/p > 0.8$. The expected background level is shown in Table 9.

The rejection power against $K^+ \to \pi^+\pi^+\pi^-$ must be greater than 10^5 to achieve a background level of $\sim 1\%$ in K^c_{e4}. Such $K_{3\pi}$ decays are rejected with the selection requirements $0.9 < E_{cal}/p < 1.1$, $P_T > 10$ MeV/c and good vertex quality.

Table 9: Background among selected K^c_{e4} decays

Decay mode	Branching Ratio	Background in K^c_{e4}
$K^+ \to \pi^+\pi^0 \to Dalitz$	2.5×10^{-3}	$\leq 0.3\%$
$K^+ \to \pi^+\pi^0\pi^0 \to Dalitz$	4.2×10^{-4}	$\leq 0.2\%$
$K^+ \to e^+\nu_e\pi^0 \to Dalitz$	5.8×10^{-4}	$\leq 0.1\%$
$K^+ \to \mu^+\nu_\mu\pi^0 \to Dalitz$	3.8×10^{-4}	$\leq 0.1\%$

Table 10 summarise the level at which $K_{3\pi}$ decay is expected to be indistinguishable from the K^c_{e4} signal:

Table 10: $K_{3\pi}$ decays contribution to the background in selected K^c_{e4}

$K^+ \to \pi^+\pi^+\pi^-$ decay	Background in K^c_{e4}
π with $0.9 < E_{cal}/p < 1.1$	4%
$K+ \to \pi^+\pi^+\pi^- \to \delta$ ray > 1 GeV	$\leq 0.1\%$
$K+ \to \pi^+\pi^+\pi^- \to e\nu_e(Br = 1.2 \times 10^{-4})$	$\leq 0.1\%$
$K+ \to \pi^+\pi^+\pi^- \to \mu\nu_\mu \to e\nu_e$	$\leq 0.6\%$

The significant background of 4% remaining in K^c_{e4} comes from $K_{3\pi}$ decays when a pion has an electron signature in the calorimeter. The pion rejection will be improved by use of the TRD detector proposed.

Preliminary MC studies show that we can expect an error of $\delta(a^0_0) < 0.01\%$ on the corresponding parameter.

7 Summary

7.1 Expected results

The following main results are expected to be obtained in one year of running of the experiment with the simultaneous K^+/K^- beams:

- More than 2×10^9 $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ and 1.2×10^8 $K^\pm \to \pi^0\pi^0\pi^\pm$ fully reconstructed decays will be be collected. Such statistics allows A_g to be measured with a precision better than 2.2×10^{-4}, and A^0_g to better than 3.5×10^{-4}, including the estimated systematic uncertainties.
- More than 10^6 K^c_{e4} charged kaon decays will be reconstructed at the background level of $\sim 1\%$. These should allow a^0_0 to be measured with an accuracy of 0.01 and the precision of the phase shift δ measurement to be correspondingly improved. These data would allow the size of the QCD condensate to be established.
- Up to 10^5 and 10^4 of radiative decays $K^\pm \to \pi^\pm\pi^0\gamma$ and $K^\pm \to \pi^\pm\gamma\gamma$ will be collected, respectively. An upper limit on the $K^\pm \to \pi^\pm\gamma\gamma\gamma$ decay branching ratio of $\sim 10^{-6}$ could be established. These data would allow the ChPT parameters to be measured and an upper limit on the CP-violation asymmetry A'_g to be estimated.
- More than 10^8 K^c_{e3} events to be recorded which would allow the scalar and tensor form-factors to be precisely measured.

Thus the proposed experiment with the novel simultaneous K^+/K^- beams and the addition of the TRD for improved electron identification, will provide data of the unique quality on several decay modes of charged kaons. We are confident that the expected results, especially in searching for direct CP-violation, given the experimental strategy adopted, similar in principle to the one successfully exploited by NA48 for the measurement of ϵ'/ϵ, will be the most precise in comparison with other experiments which to our knowledge are at present running or in preparation.

7.2 Resources required and responsibilities

The required resources and Institutions responsible for the relevant constructions are presented in Table 11. [7] The resources which are foreseen from the Collaboration common fund are labelled as Collaboration.

Table 11: Resources required and responsibilities

Required resources	Responsible Institutions	Cost estimates in kCHF
SPS beam: 400 GeV protons, duty cicle of 5/19.2 s, 10^{12} p/p/p on T10	CERN	
K^+/K^- beam construction	CERN	140.0
NOMAD TRD reconstruction	CERN, Ferrara, Dubna	100.0
TRD gas supply system	CERN, Collaboration	100.0
TRD electronics	Ferrara	540.0
NA48 setup operation	Collaboration	

The group from Saclay is going on to continue the research and development of the MICROMEGAS detector in order to estimate it possible application for the beam spectrometer.

[7] It is assumed that the drift chambers have been repaired prior to this programme.

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