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Status Report on the Experiment NA48/2

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Contents

1 Introduction

A high precision study of charged kaon decays is performed using a novel design for simultaneous K^+/K^- beams and an upgraded NA48 set-up [1]. The main goal is to search for direct CP-violation in $K^\pm \to \pi^+\pi^-\pi^\pm$ decays, which is defined by the asymmetry parameter

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

where g^+ and g^- are the slope parameters describing, respectively, the linear dependence of the K^+ and K^- decay probabilities on the u kinematic variable of the Dalitz plots. The u variable is related to the energy (E^*_{odd}) of the *odd* pion (the pion having the distinguished sign) in the kaon center of mass system. The corresponding asymmetry parameter A^0_g in $K^\pm \to \pi^0\pi^0\pi^\pm$ decays is measured as well.

Calculations based on the Standard Model (SM) predict A_g (A^0_g) values to be between $(2.3 \pm 0.6) \cdot 10^{-6}$ [2] and $\sim 5 \cdot 10^{-5}$ [3][4][5]. However, in SUSY models this asymmetry could be as high as $\sim 3 \cdot 10^{-4}$ [6], and in some specific models even up to $\sim 7 \cdot 10^{-4}$ [7].

There only few data on the measurement of A_g is based on $\sim 3 \cdot 10^6$ decays, giving $A_g = (-7.0 \pm 5.3) \cdot 10^{-3}$ [8]. The preliminary result of the HyperCP experiment at FNAL having higher statistics is $(2.2 \pm 1.5 \pm 3.7) \cdot 10^{-3}$[9]. These data are complemented by results obtained for A^0_g in the Serpukhov experiments: $(5.1 \pm 2.8) \cdot 10^{-3}$[10], and $(0.2 \pm 2.9) \cdot 10^{-3}$[11]. All the above experiments determined the slopes by running with just one sign beam and comparing with the PDG value for other sign, or running alternately with beams of either sign.

The NA48/2 experiment is designed to reach a sensitivity, limited by statistics rather than systematics, better than $\sim 2 \cdot 10^{-4}$ in the measurement of A_g and slightly worse in the measurement of A^0_g due to the smaller branching ratio and acceptance of this decay. An observation of the asymmetries at this level would be considered as an indication of a new physic evidence.

Charged kaon rare decays are studied as well.

High statistics ($\sim 10^6$) of K_{e4} will be analyzed allowing the $\pi - \pi$ scattering length parameter a^0_0 to be measured with an accuracy of 0.01 (5%). This allows the size of the $q\bar{q}$ condensate of the QCD vacuum to be measured at rather precise way.

The present knowledge of several rare decays of the charged kaon such as:

$K^\pm \to \pi^\pm\pi^0\gamma$,

$K^{\pm} \to \pi^{\pm}\pi^{0}\gamma\gamma$,
$K^{\pm} \to \pi^{\pm}\pi^{0}\ell^{+}\ell^{-}$,
$K^{\pm} \to \pi^{\pm}\ell^{+}\ell^{-}$,
$K^{\pm} \to \ell^{\pm}\nu\ell^{+}\ell^{-}$
and others, can be extended as well. This will allow χPT predictions at next-to-leading order to be tested.

At the same time semileptonic decays of $K^{\pm}$ are studied in order to measure the V_{us} element of the CKM matrix with better precision than currently available, and leptonic decays of charged kaon are measured to perform a high precision test of lepton universality in these decays.

The experiment NA48/2 [12] was approved by the CERN Research Board in 2000. Data taking has been carried out at CERN SPS in 2003 and 2004.

2 NA48/2 Experiment Configuration

The new K12 beam line has been designed and built to transport simultaneously positive and negative particles with central momentum 60 GeV/c to the upgraded NA48/2 detector in the underground hall ECN3 at the SPS (fig.1).

2.1 Simultaneous K^{+}/K^{-} beams

Charged particles are produced in a Be target by 400 GeV/c primary protons with a chosen intensity of $7 \cdot 10^{11}$ ppp (with 16.8s cycle time and 4.8s flat-top). The two beams of opposite charge originating at zero degrees relative to the primary proton direction, each have an acceptance opening angle of ± 0.36 mrad in both planes. The momentum band for the two charges is selected by a 'front-end achromat', consisting of 4 MTR-type dipole magnets with deflections in the vertical plane. The distribution of selected momenta for both charges has a width of $\pm 3.8\%$ (r.m.s.). A system of four alternating-gradient quadrupoles is used to focus particles of each sign similarly in both planes at the spectrometer position. The positive beam flux at the exit of the final collimator was estimated to be $3.8 \cdot 10^{7}$ ppp (of which $2.2 \cdot 10^{6}$ were K^{+}); the negative beam flux was $2.6 \cdot 10^{7}$ppp (with $1.3 \cdot 10^{6}$ K^{-}). The corresponding fluxes of muons from K and p decays in the 114m long decay volume were $\sim 2 \cdot 10^{6}$ per pulse. More detailed description of these beams could be found elsewhere [12].

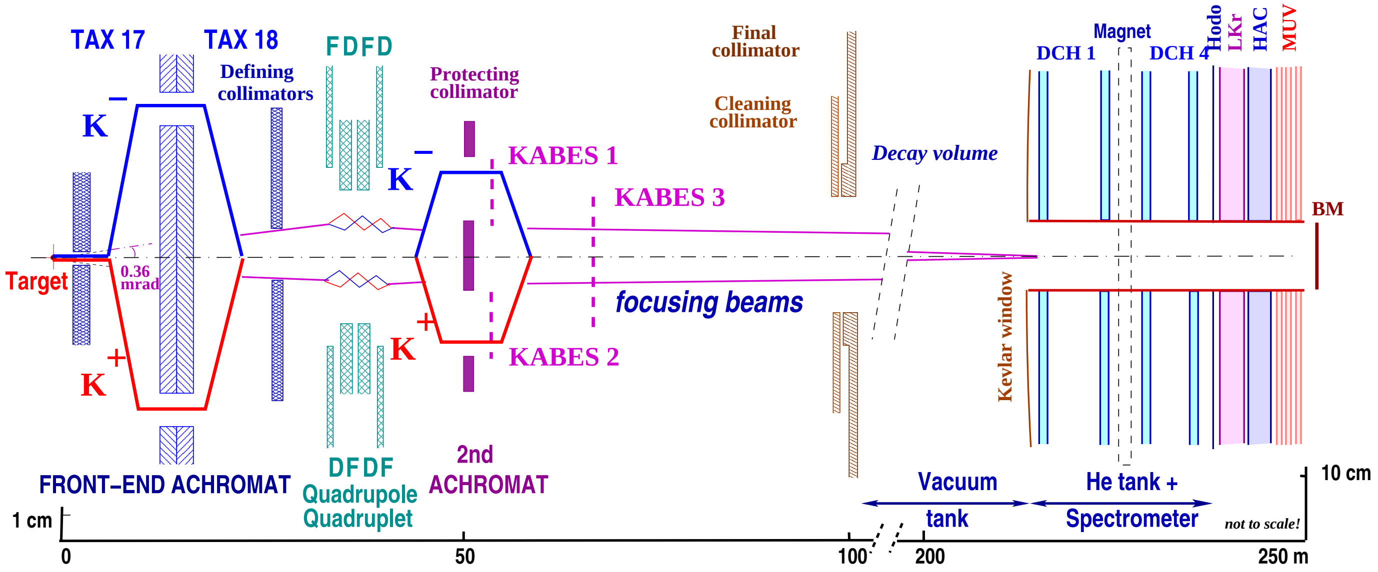

Fig. 1: The NA48/2 experiment configuration: the beam line and the Set-Up. The purple lines show the transverse envelope of both superimposed beams, which are split in the two achromats and are focused at the center of the detector.

Some residual charge-dependent structure were detected inside the focused beam spots during the2003 run. Such structures were reduced to being non-observable during the winter 2003 - 2004 shutdown: the alignment of the four beam-line focusing quadrupoles was checked and readjusted; the small deflections of the two beams by the stray field of the main muon sweeping magnets have been corrected; the pair of steering magnets has been reconnected to separate power converters making possible to separate corrections for the beam positions and for any residual quadrupole misalignment. As a result the K^+ and K^- beams are brought onto a common axis at the exit of the final collimator within a precision of $< 1mm$ in the run 2004. The beam spot shape as a function of momentum was similar for both beams in 2004, while a small difference was observable in 2003 for negative kaons (see. figs.2).

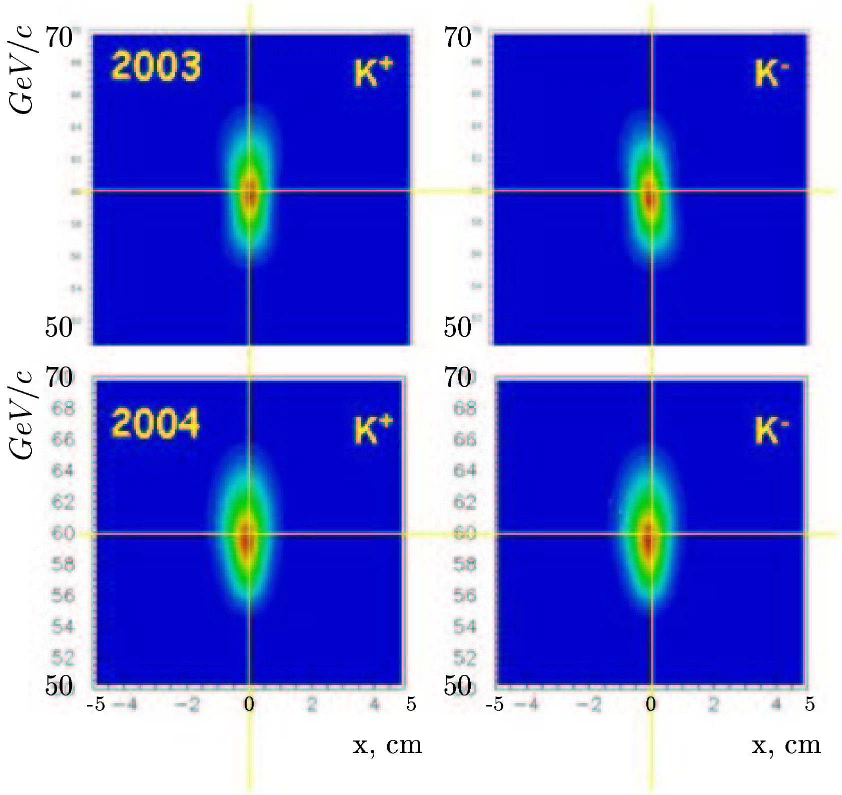

Fig. 2: The correlations of the beam positions with the kaon momenta in 2003 and 2004 runs

2.2 Upgraded NA48 Set-Up

The basic elements of the NA48 set-up (fig.1) include: a magnetic spectrometer with the dipole magnet MNP33 and four drift chambers (DCH1-4), each having 8 signal planes, positioned in the He tank at atmospheric pressure; hodoscope of scintillating counters (Hodo) used for generating the L1 trigger signals; liquid krypton (LKr) electro-magnetic calorimeter; hadronic calorimeter (HAC); muon filter (MUV); system of anticounters surrounding the vacuum decay volume, which is separated by a thin kevlar window from the He tank [1].

In order to adapt the NA48 set-up to the study of charged kaon decays several elements were modified or upgraded: the decay vacuum tank was extended upstream by 24m increasing the acceptance for $K^{\pm} \rightarrow (3\pi)^{\pm}$ decays by $\sim$ 30%; a new beam spectrometer KABES [13] was integrated into the beam line to provide a precise momentum measurement of the incident $K^{\pm}$; the third drift chamber (DCH3) was fully instrumented; the electronics of all drift chambers (DCH1-4) were reorganized in order to achieve left-right (*Jura-Saleve*) symmetry of possible read-out inefficiencies; a special beam monitor (BM) was installed at the end of the experimental hall to monitor on-line the shapes and positions of the two beam spots.

2.3 Trigger Logics

The basic trigger logics were designed and optimized in 2003 and further developed in 2004. The trigger is based on a pre-trigger selection, provided by the hodoscope multiplicity fast logic, and a second level (L2) selection, based on the on-line processing of the information from the LKr calorimeter and drift chambers. Out of an input rate of $1MHz$, a rate of $10kHz$ triggers to be readout was obtained.

The trigger for the $K^{\pm} \rightarrow \pi^{\pm}\pi^{-}\pi^{+}$ and K_{e4} decays selected events with 3 charged tracks. A pre-trigger required at least 2 tracks in the hodoscopes, with no in-time signals from the ring anti-counters. The level 2 trigger processor farm ('massbox') asynchronously handled pre-trigger events by analyzing the data from DCH's with a total time budget of 100 μs to take a decision. The basic algorithm, which required two compatible vertexes in the fiducial region, was complemented with a second one, looking for a single vertex compatible with the $K^{\pm} \rightarrow (3\pi)^{\pm}$ decay kinematic. The combination of these triggers had an overall inefficiency around 1%.

Triggers for $K^{\pm} \rightarrow \pi^{\pm}\pi^{o}\pi^{o}$ and other events with a single charged track and photons exploited the common pre-triggers based on the detection of electro-magnetic energy in the calorimeter (LKr). The on-line kinematic reconstruction at L2 and the narrow range of beam momenta (assuming 60 GeV/c kaons directed along the Z-axis) allow for triggering on both three tracks events, including $K^{\pm} \rightarrow \pi^{\pm}\pi^{-}\pi^{+}$ and K_{e4}, and one track events including $K^{\pm} \rightarrow \pi^{\pm}\pi^{o}\pi^{o}$, with adequate missing mass cut in order to reject the main background from $\pi^{\pm}\pi^{o}$.

A part of the readout bandwidth was used to control these triggers as well as other rare decay triggers.

In 2004 a 20% larger effective bandwidth was obtained by reading out the LKr calorimeter information only for a fraction of 70% of the three tracks events. While this selective readout is not spoiling the analysis of the $K^{\pm} \rightarrow \pi^{\pm}\pi^{-}\pi^{+}$ events it allowed for some additional 10000 events to be readout for a total of 60000 events per burst. The additional triggers were used as follows:

- to enhance the efficiency of the one track trigger by loosening the pre-trigger selection in input to L2;
- to provide an additional L2 control trigger for one track events, based only on LKr calorimeter information. As this trigger had no need for downscaling, it allows a precise measurement of the trigger inefficiency, which is important for the measurement of the charge asymmetry in the $K^{\pm} \rightarrow \pi^{\pm}\pi^{o}\pi^{o}$ channel;
- to provide dedicated one track triggers for special studies concerning the channel $K^{\pm} \rightarrow \pi^{\pm}\nu\overline{\nu}$;
- to allow a dedicated trigger for events with no tracks detected in the spectrometer useful for collecting $K^{\pm} \rightarrow \pi^{\pm}\pi^{o}\pi^{o}$ events where the $\pi^{\pm}$ missed detection;
- to provide additional control triggers for various other channels (for instance the K_{e2}) which in 2003 suffered for lack of bandwidth;

Additional trigger signals from the drift chambers were made available in 2004 for use in specific triggers.

The overall performance of the trigger in 2004 run was quite good. The dead time was kept at a very low level (below 10^{-3}). The efficiency is almost at the same level as in 2003 for three track events; in case of $K^{\pm} \rightarrow \pi^{\pm}\pi^{-}\pi^{+}$ it is above 98%. Concerning one track events the efficiency is better than in 2003: for instance it is above 94% for both $K^{\pm} \rightarrow \pi^{\pm}\pi^{o}\pi^{o}$ and $K^{\pm} \rightarrow \pi^{\pm}\pi^{o}\gamma$.

Moreover, due to additional control triggers, the efficiency can be measured with better accuracy than in 2003.

The Level 3 software trigger ran in flagging mode (that is not cutting events) since the beginning of the run, with a complete set of selection algorithms, allowing both a constant and fast monitoring of the data quality in the control room, and a quick and efficient way of selecting particular classes of events for further reprocessing.

3 Data taking

In order to achieve the required sensitivity, the strategy of data taking has been chosen in accordance with the highest possible immunity to detector asymmetries and perturbation. This requires time stability of the experimental conditions. To minimize systematic uncertainties the magnetic field was alternated in the spectrometer magnet on a daily basis in 2003 and every 3-4 hours in 2004. In addition, all the beam line magnets (including the quadrupoles) were cycled and inverted usually once per week during the machine development (MD) pauses. The latter frequency was chosen to minimize losses of data, since the procedure is rather long and requires subsequent retuning of the beams, which in any case needed to be done after the MD. Thus a complete data-set, collected with both beam line orientation, called a *supersample*, was accumulated usually over a two-week period.

The data have been taken in two runs: from June 12 to September 8 in 2003, and from May 15 to August 8 in 2004.

Taking into account the time spent for the new beam tuning, putting the upgraded Set-Up into operation and absence of the beam, $\sim$ 50 days were available for data taking in 2003. In total, more than 30 days were lost for data taking in 2003 due to problems not under control of the Collaboration, the major causes of which were: absence of beam, cooling problems, and the after-effects of power cuts. Only during one month of 2003 from August 6 to September 7 (period 2003–II) the data was collected in a relatively stable conditions. In this period two complete *supersamples* and a smaller one were accumulated. The previous period (2003–I) which was characterized by frequent beam interruptions, is less efficient for the asymmetry measurement and the corresponding data analysis requires more detailed evaluation of systematics.

The start of data taking in 2004, despite the discovery of the broken kevlar window, was in time with the PS start-up, thanks to a quick repair.

The data in 2004 have been taken in two periods separated by the special 25 ns run and the scrubbing run (both not useful for data taking). In the first period from May 15 to June 6, after a short start-up tuning, the data were collected already at a good rate, except for the period where the PS septum was broken. As soon as normal proton beam running restarted the data taking has been continued even during the period were the PS septum was run without cooling. During the second period, the readout of the experiment was modified to discard calorimeter data for a fraction of the $K^{\pm} \rightarrow (3\pi)^{\pm}$ decay candidates. Doing that we were able to collect a larger amount of triggers with the same number of good $K^{\pm} \rightarrow (3\pi)^{\pm}$ decay candidates, but allowing some bandwidth to be used to collect more control triggers as described in the 2.3 section.

Having detected a slow drift of the spectrometer alignment in 2003, muon runs were taken at regular intervals (usually twice per month) in 2004 to monitor the alignment of the spectrometer which has been found to be stable within $20\mu m$. The on-line reconstructed masses of $K^{+}_{3\pi}$ and $K^{-}_{3\pi}$ decay are very similar (fig.3) and the corresponding ratio was rather stable in time.

A total of 11 billions of triggers were collected in 2004 for a total amount of $\sim$ 120 TB of data. Five *supersamples* of different duration have been recorded in 2004.

The relevant statistics of raw $K^{\pm} \rightarrow (3\pi)^{\pm}$ decays reconstructed in 2003 and 2004 runs are presented in Table 1.

Periods of data taking	$K^{\pm}$ *decays, 10^6*		# of *supersamples*
	$\pi^{\pm}\pi^{+}\pi^{-}$	$\pi^{\pm}\pi^{0}\pi^{0}$	
2003–I	$\sim$ 600	$\sim$ 20	non stable
2003–II	1300	50	3
2004	2150	130	5
Total	$\sim$ 4050	$\sim$ 200	8

Table 1: Accumulated statistics of raw $K^{\pm} \rightarrow (3\pi)^{\pm}$ decays, in millions. For the asymmetry analysis the effective statistics will be reduced due to acceptance related cuts. Additional losses might be introduced due to rejection of bursts with detector or electronics malfunction.

The preliminary results based on the analysis of three *supersamples* collected in $\sim$ 1 month of data taking in 2003 (period 2003–II) are presented below.

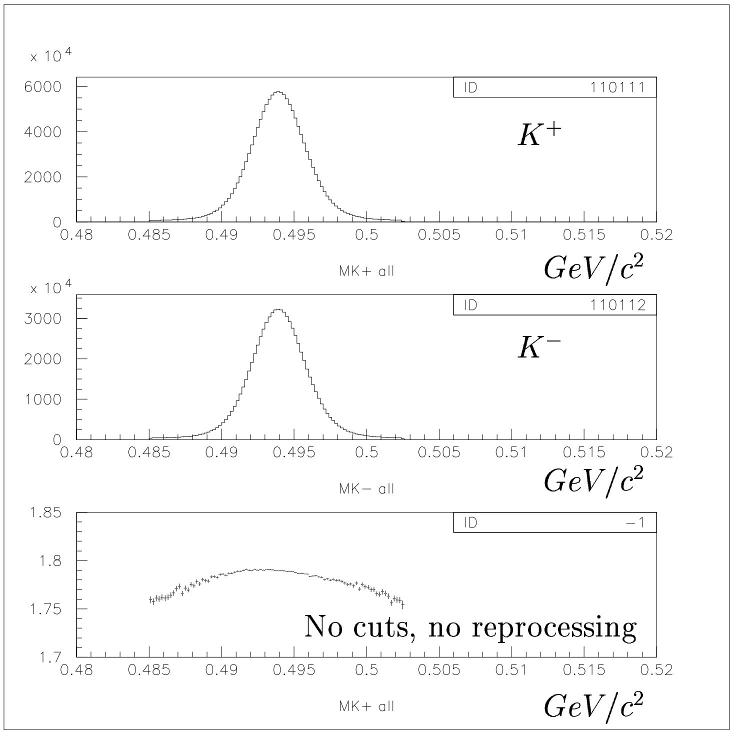

Fig. 3: The invariant masses of $K^+ \to \pi^+\pi^+\pi^-$ and $K^- \to \pi^-\pi^-\pi^+$ decays, and their ratio reconstructed on-line in the 2004 run.

4 Asymmetry measurement

The invariant mass spectra of reconstructed $K^+ \to \pi^+\pi^+\pi^-$ and $K^- \to \pi^-\pi^-\pi^+$decays (figs. 4 (a) and (b)) indicate a negligible background level. A fine calibration of the spectrometer magnetic field has been done by adjusting the global momentum scale (at the $\sim 10^{-3}$ level) for each day-sample separately equalizing the corresponding average value of the reconstructed K^+ and K^- masses to the PDG value. Small time variations of the DCH alignment ($\sim 4\mu m/day$) were detected in 2003 and corresponding time dependent corrections have been introduced in the position of DCH4 along the x-axis ($\leq 50\mu m$) and, as a consequence, in the pion momenta. In this way the time stability of the data is improved.

To reduce the acceptance asymmetry for positive and negative kaon decays caused by the different relative beam positions and to minimize any time variation of such differences the selection criteria include radial cuts around the measured beam positions. These positions are defined by the

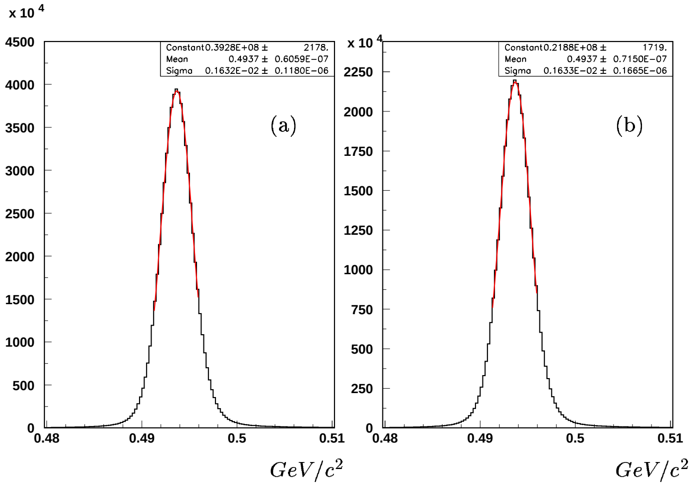

Fig. 4: Reconstructed mass spectra for the decays $K^+ \to \pi^+\pi^+\pi^-$ *(a) and* $K^- \to \pi^-\pi^-\pi^+$ *(b).*

centers of gravity (COG) for positive and negative kaon decay products and were evaluated in short time periods. After the final selection ~ 630 million $K^+ \to \pi^+\pi^+\pi^-$ decays and ~ 350 million $K^- \to \pi^-\pi^-\pi^+$ decays remain. The Dalitz-plot $(u, |v|)$ for selected $K^\pm$ is presented in fig.5. The indicated kinematic variables are defined as:

$$u = 2M_K/m^2(M_K/3 - E^*_{odd}), v = 2M_K/m^2 \mid \Delta E^* \mid,$$

where M_K and m are the kaon and pion masses, respectively, E^*_{odd} is the energy of the *odd* pion and ΔE^* – energy difference of two other (*even*) pions, all in the kaon center of mass system.

The CP-violating asymmetry parameter A_g could be measured from the ratio

$$R(u) = constant \cdot (N^+(u)/N^-(u)),$$

where: $N^+(u)$ and $N^-(u)$ are the u spectra of $K^+ \to \pi^+\pi^+\pi^-$ and $K^- \to \pi^-\pi^-\pi^+$ decays, respectively, and the *constant* provides the normalization of $R(0) = 1$. Two such ratios are considered:

$$R_S(u) = N^+(u)_U/N^-(u)_D$$

and

$$R_J(u) = N^+(u)_D/N^-(u)_U,$$

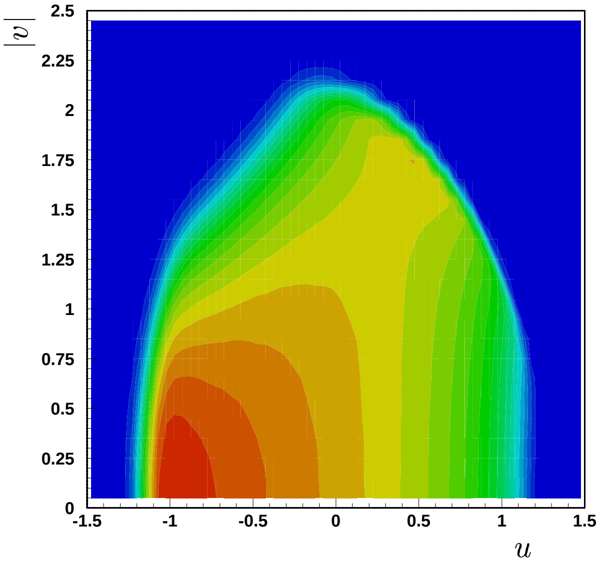

Fig. 5: Dalitz-plot for $K^{\pm}$.

where the subscripts U and D indicate the direction of the field (*Up* and *Down*) in the spectrometer magnet. The subscripts S and J are chosen to indicate the direction of deflection of pions of the same charge as the kaon by the spectrometer magnet toward the *Saleve* and *Jura* sides. In case of perfect time stability these ratios would show a linear dependence on u. The corresponding slopes A_S, A_J, would be identical and, to first order, equal to Δg, which is related to A_g according to:

$$\Delta g = g^+ - g^- = 2g \cdot A_g,$$

where g is the average of g^+ and g^- ($g \simeq 0.24$ [14]). In this case any time stable *Saleve* - *Jura* acceptance asymmetry affects neither A_S nor A_J. Eventual time instable asymmetries cancel in the average

$$A = 0.5 \cdot (A_S + A_J).$$

Thus a deviation from zero of A would be an evidence of a CP-violating asymmetry, as long as the set-up is either stable in time or *Saleve* - *Jura* symmetric.

Two additional ratios:

$$R^+(u) = N^+(u)_U / N^+(u)_D$$

and

$$R^{-}(u) = N^{-}(u)_U / N^{-}(u)_D,$$

which do not contain information on A_g and can only be non-flat due to instrumental effects, were studied as well. The corresponding slopes A^+ and A^- could be considered as control asymmetries. They are sensitive to the *Saleve - Jura* acceptance asymmetry, but their average $(A^{\pm})$ should be equal to zero in case of perfect time stability and the above conditions are fulfilled.

As a cross-check the analysis was performed independently in 10 kaon momentum bins (from 56 GeV/c to 66 GeV/c) of 1 GeV/c each (the corresponding resolution is $\sim 0.4\ GeV/c$) Alternatively the analysis is done in 9 bins of kaon decay vertex position along the beam line (Z-coordinate) 10 m each.

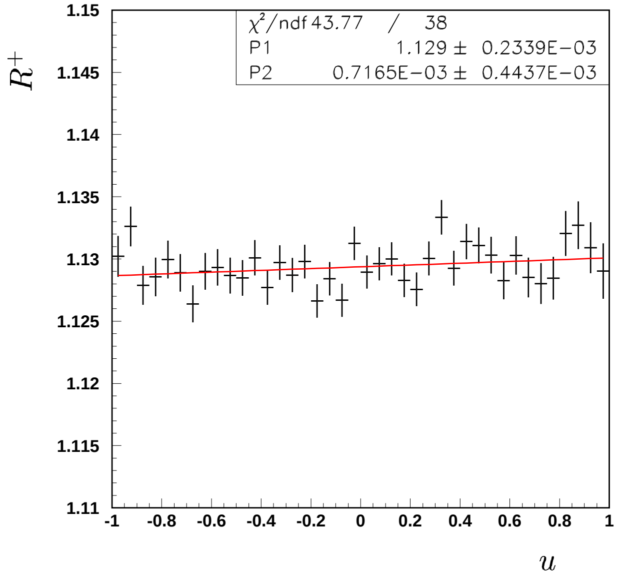

Fig. 6: Linear fit of the ratio $R^+(u)$ for kaon momentum interval 58–59 GeV/c.

An example of linear fit of the ratio $R^+(u)$ for kaon momentum interval 58–59 GeV/c is presented in fig.6. The slopes A^+ and A^- obtained for the selected events in each momentum bin as well as their averages $(A^{\pm})$ are shown in figs.7 (c) and (d). Similar slopes obtained for different positions of kaon decay vertexes are presented in figs.8 (c) and (d).

The average unphysical slopes $(A^{\pm})$'s integrated over all the momentum bins, or over all the decay vertexes, were measured to be compatible with zero within two standard deviations:

$$< A^{\pm} >= (2.6 \pm 1.3) \cdot 10^{-4}.$$

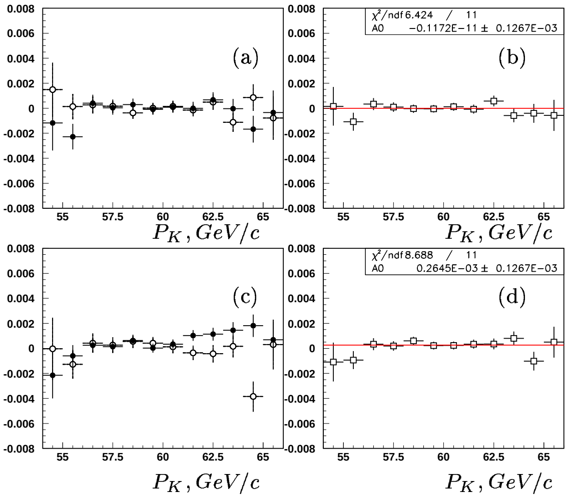

Fig. 7: The slopes reconstructed for different kaon momenta: (a)A_S (black circles) and A_J (open circles) with an offset on the vertical scale, (b) A- the averages of A_S and A_J with an offset on the vertical scale, (c) A^+ (black circles) and A^- (open circles); (d) $A^{\pm}$ - the averages of A^+ and A^-.

The corresponding plots obtained for A_S, A_J and A with similar selection criteria are presented in figs.7 (a) and (b) and in figs.8 (a) and (b) with an offset for the vertical scale in order to shadow results at this preliminary stage of analysis. These plots do not indicate any *Saleve* - *Jura* acceptance asymmetry or momentum dependent effects at the level of the statistical precision of $\pm 1.3 \cdot 10^{-4}$.

To check the time stability all the studied asymmetries integrated over all the momentum bins (over all the decay vertex bins) were obtained for each couple of *day-samples.* The corresponding time dependent distributions obtained for A_S, A_J and A are plotted in figs.9 (a) and (b) with offsets, and the ones obtained for A^+, A^- and $A^{\pm}$ are plotted without offsets in figs.9 (c) and (d). All these plots do not indicate any significant variation in time and allow to conclude that the *Saleve* - *Jura* acceptance asymmetry is equalized

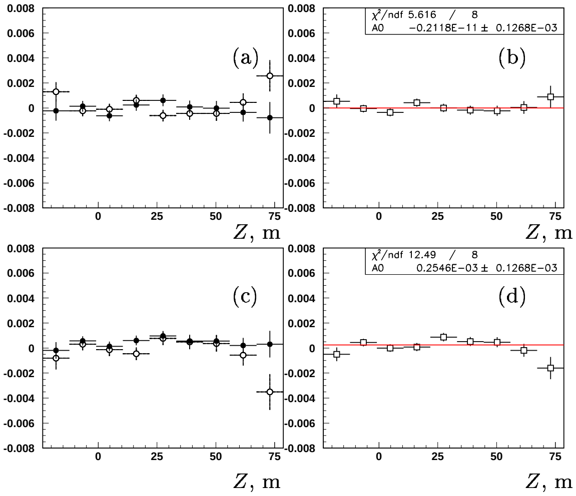

Fig. 8: The slopes obtained for different vertexes of kaon decays: (a)A_S (black circles) and A_J (open circles) with an offset on the vertical scale, (b) A- the averages of A_S and A_J with an offset on the vertical scale, (c) A^+ (black circles) and A^- (open circles); (d) $A^{\pm}$ - the averages of A^+ and A^-.

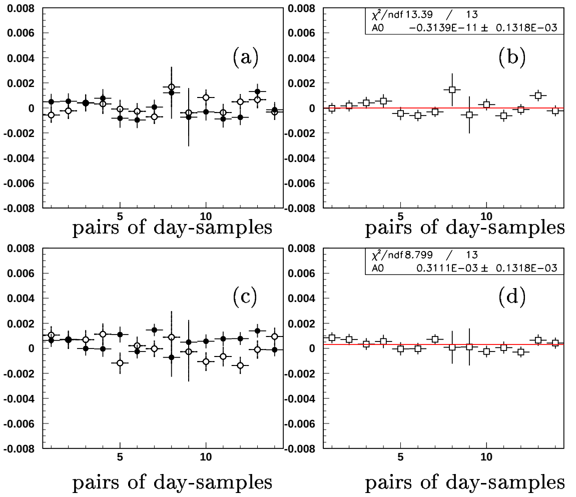

Fig. 9: The slopes obtained for the different pairs of day-samples: (a) A_S (black circles) and A_J (open circles) with an offset on the vertical scale, (b) A- the averages of A_S and A_J with an offset on the vertical scale, (c) A^+ (black circles) and A^- (open circles), (d) $A^{\pm}$ - the averages of A^+ and A^-.

for $K^+_{3\pi}$ and $K^-_{3\pi}$ decays, and is sufficiently stable in time within the chosen period of data taking.

Other possible systematic effects related to the residual magnetic fields, accidental events and the DCH and trigger inefficiencies have been found not to affect the measured slopes at the present level of precision. We conclude that there are no uncontrolled effects visible in the data and that therefore possible residual systematic uncertainties do not exceed the statistical precision achieved so far.

The presented analysis corresponds to a statistical precision of the measured asymmetry

$$< A_g >= offset \pm 2.7 \cdot 10^{-4}.$$

Which is already more than one order of magnitude better than what is currently known.

A similar analysis based on 38 million $K^\pm \to \pi^\pm\pi^0\pi^0$ selected decays has been performed. The corresponding mass spectra for selected decays of K^+ and K^- are presented in the figs.10 (a) and (b), respectively. The preliminary study of the corresponding asymmetry leads to a precision of

$$< A^0_g >= offset \pm 5.0 \cdot 10^{-4}.$$

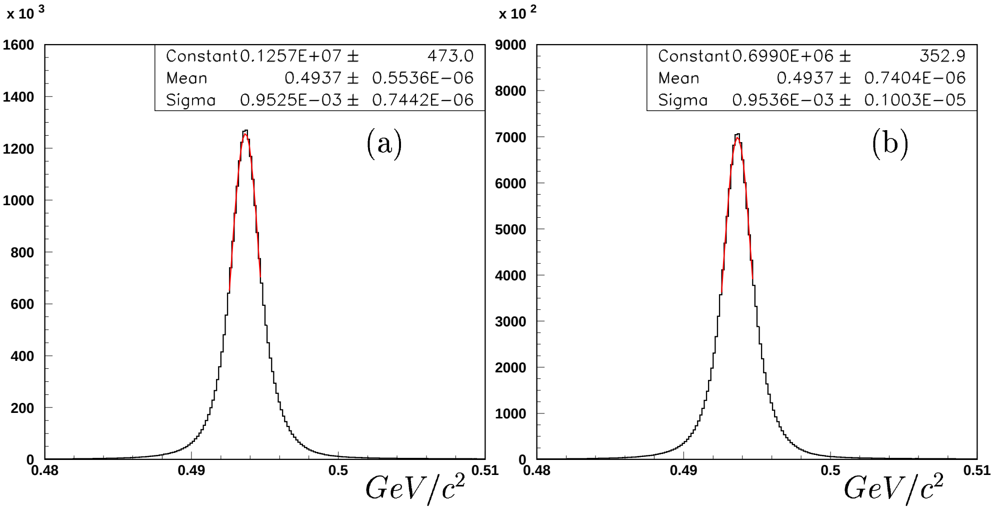

Fig. 10: Reconstructed mass spectra for the decays $K^+ \to \pi^+\pi^+\pi^-$ *(a) and* $K^- \to \pi^-\pi^-\pi^+$ *(b).*

Further study of all the data taken by the NA48/2 experiment will lead to more precise results.

5 Rare decays

Preliminary analyses were started on some rare decay modes to select several rare kaon decays and estimate the corresponding background.

5.1 K_{e4}

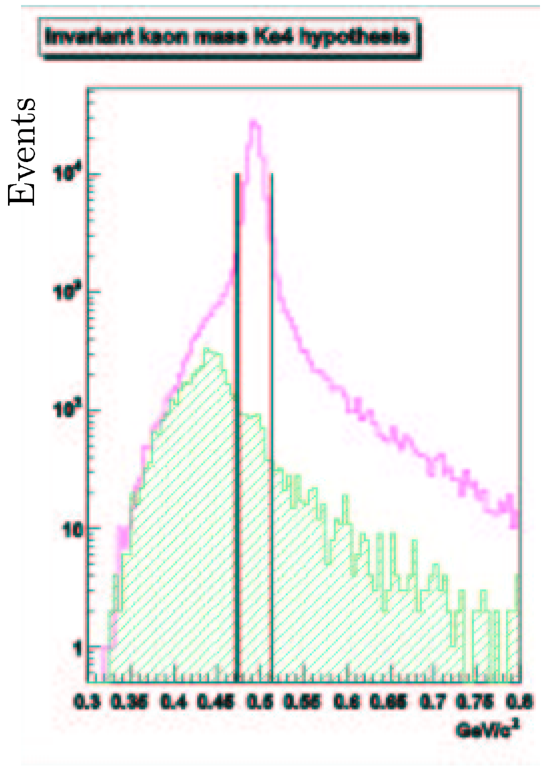

Fig. 11: Invariant mass spectrum of K_{e4} *decays reconstructed and selected under assumption of nominal kaon momentum directed along the Z-axis (dashed histogram indicates the background).*

To estimate the quality of K_{e4} events tight criteria were used to select fully reconstructed decays exploiting the rather precise knowledge of the kaon momentum from the beam, while the new beam spectrometer, which will provide a more accurate measurement of such quantity on an event-by-event basis to be used for the final analysis, was calibrated and integrated in the reconstructed program. The corresponding invariant mass reconstructed for more that 300 thousand decays selected is presented in fig.11. A neural network method based on information from the electro-magnetic calorimeter was used for $\pi - e$ separation. The background arising from residual $e - \pi$ misidentification and related mainly to the $K^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm}$ decays and $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ followed by a Dalitz decay $\pi^{0} \rightarrow e^{+}e^{-}\gamma$, has been estimated at the level of $\sim 0.6\%$. The corresponding distributions on the Cabibbo-Maksymowicz kinematic variables used to extract the form factors of the decay are presented in figs.12.

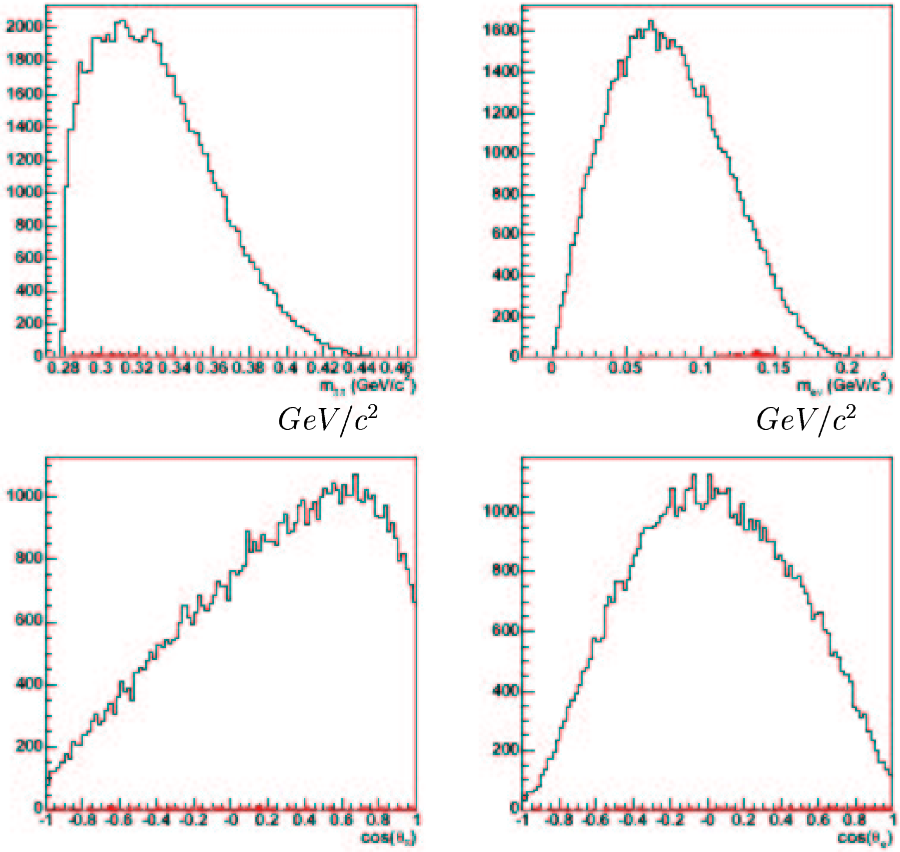

Fig. 12: Distributions on the Cabbibo-Maksymowicz variables of the selected K_{e4} decays (dashed plot indicate the background)

The low level background level allows to extract relevant physical parameters with minimal biases. In total more than $5 \cdot 10^5$ K_{e4} events are expected only in the 2003 data. The analysis is in progress now.

5.2 Other rare decays

A study of charged kaon rare decays $K^\pm \to \pi^\pm e^+ e^-$ and $K^\pm \to \pi^\pm \mu^+ \mu^-$ is dedicated to precise measurement of the branching ratios and corresponding form factors. These allow to separate direct and indirect bremsstrahlung mechanism contributions to the decays and to test the χPT predictions at next to leading orders. A search for corresponding charge asymmetries would establish additional limits on the CP violation effects.

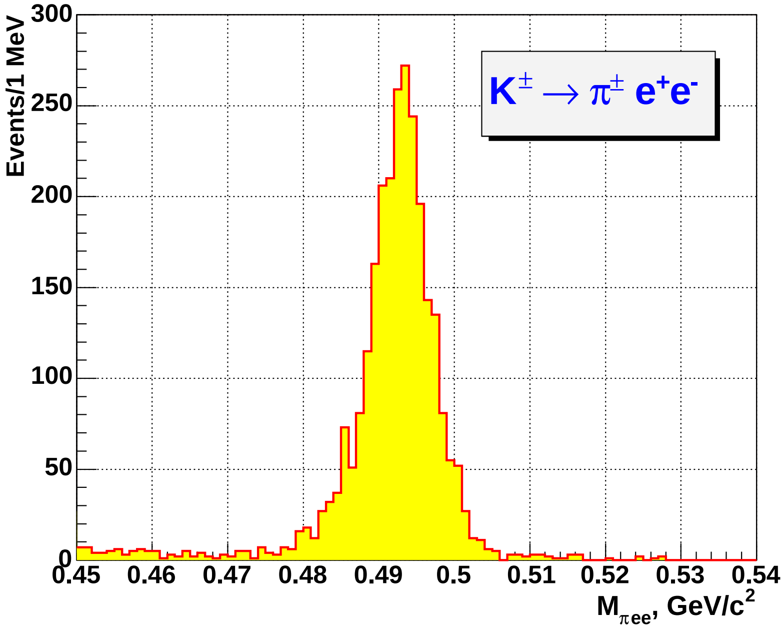

Fig. 13: $K^\pm \to \pi^\pm e^+ e^-$ *invariant mass spectrum obtained in period 2003-II.*

Around 2600 $K^\pm \to \pi^\pm e^+ e^-$ decays have been selected from the data accumulated in the period 2003-II. The corresponding mass spectrum obtained for the decays selected in the kinematic region of $m(e^+e^-) > 140 MeV/c^2$ in presented in fig.13. The background level for the selected events is below: 2%. The distribution on z-variable $(z = (m(e^+e^-)/M_K)^2)$ of the selected decays presented in fig.14 allows to extract information on the form factor.

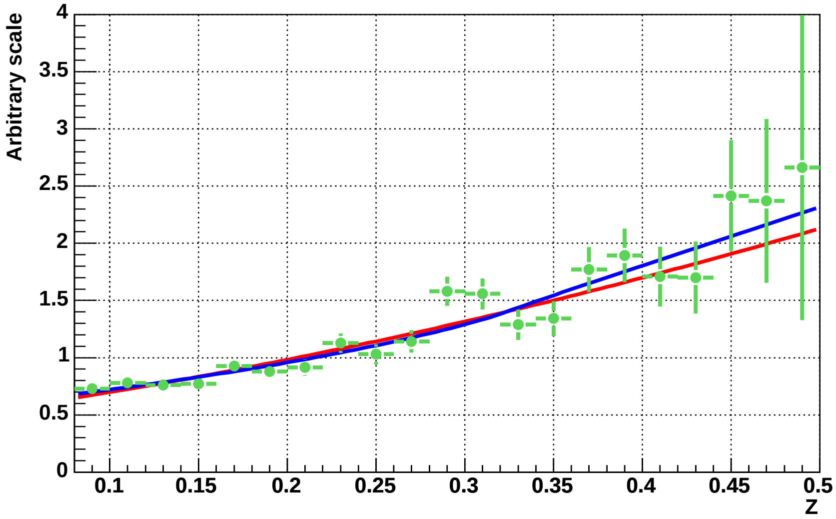

Fig. 14: The distribution of the selected $K^{\pm} \to \pi^{\pm}e^{+}e^{-}$ decays over the kinematic variable z. The two curves indicate the fits by linear and quadratic form factors.

Fig.15 shows the invariant mass spectrum for the selected $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ decays candidates. The peak in this plot contains $\sim$ 1000 events, which is more than the current world statistics.

The $K^{\pm} \to \pi^{\pm}\gamma\gamma$ decays can be studied in two kinematic regions defined by cuts on $m(\gamma\gamma)$ which are required to reject the background of $K^{\pm} \to \pi^{\pm}\pi^{0}$ decays. This rejection is done already at the trigger level. A study of the $m(\gamma\gamma)$ spectra allows to perform a precise check of χPT predictions at the next-to-leading order. The first estimation of the expected statistics indicate that the world sample could be enlarged by two orders of magnitude. The work is in progress.

High sensitivity studies and searches for the rare decays $K^{\pm} \to \pi^{\pm}\gamma l^{+}l^{-}$, $K^{\pm} \to \pi^{\pm}\gamma\gamma\gamma$, $K^{\pm} \to l\nu l^{+}l^{-}$, $\pi^{\pm} \to l\nu l^{+}l^{-}$ will also be performed on the accumulated data.

6 First Observation of a Threshold Effect in $K^{\pm} \to \pi^{0}\pi^{0}\pi^{\pm}$ Decays

The large statistics of fully reconstructed decays $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ ($\sim$ 29

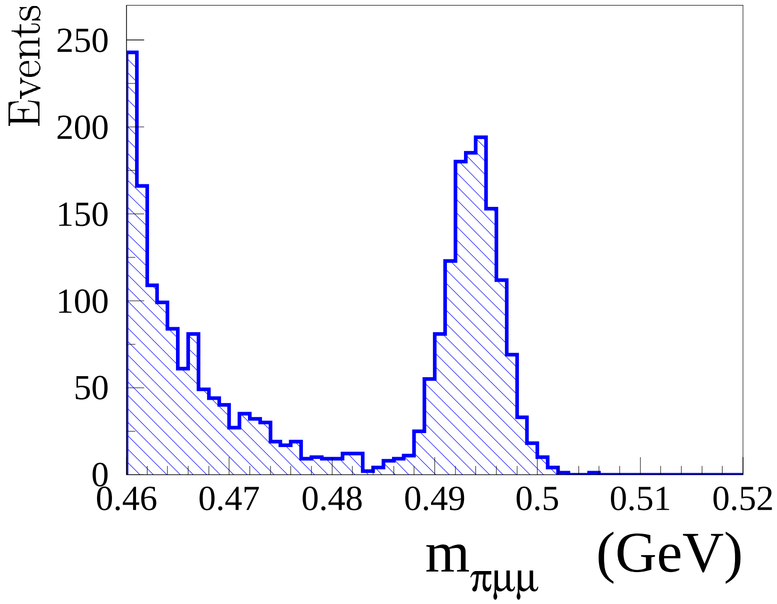

Fig. 15: The invariant mass spectrum of the final states $\pi^{\pm}\mu^{+}\mu^{-}$ obtained in the period 2003-II.

million events within acceptance cuts in the 2003-II period) coupled with excellent resolution on the $\pi^0\pi^0$ invariant mass (better than 0.5 MeV in the region around the twice the mass of charged pion) has allowed the detection of previously unpredicted structures in the distribution of events as a function of the squared invariant mass of two neutral pions $M^2(\pi^0\pi^0)$.

Fig.16(a) shows the $M^2(\pi^0\pi^0)$ distribution of reconstructed events, without any acceptance correction, for the sample of data collected during the period 2003-II.

Fig.16(b) shows the same $M^2(\pi^0\pi^0)$ distribution in the region close to $M^2(\pi^0\pi^0) = 4m^2_{\pi^{\pm}} = 0.0779(MeV/c^2)^2$. An evident break in the slope of the distribution occurs precisely at this point which corresponds to the threshold for real $\pi^+\pi^- \to \pi^0\pi^0$ charge exchange scattering, therefore allowing $K^{\pm} \to \pi^{\pm}\pi^+\pi^-$ events to contribute to the $\pi^{\pm}\pi^0\pi^0$ final state. The correction for acceptance, necessary for a fully quantitative description of the structure, is not expected to modify the observed qualitative features, since MC estimates show that the acceptance is well approximated by a smooth approximatively linear function.

This experimental finding has inspired Nicola Cabibbo to propose a parametrization of the shape close to the threshold as a function of the $\pi - \pi$

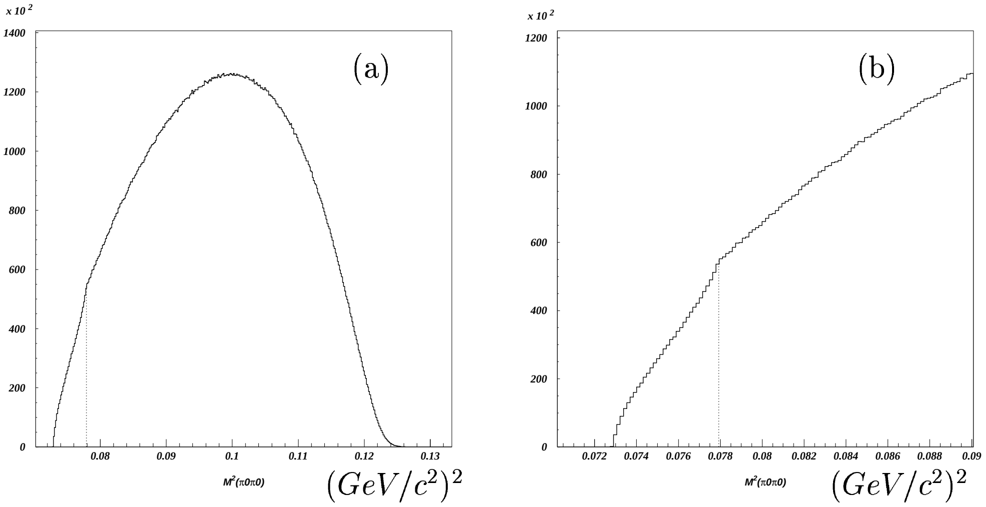

Fig. 16: The $M^2(\pi^0\pi^0)$ distribution for the subsystem of the reconstructed $K^\pm \to \pi^\pm\pi^0\pi^0$ decays: (a) – in the full kinematic region(); (b) – in the region around the threshold; the value corresponding to $4m_{\pi^\pm}^2$ is indicated by vertical line.

rescattering length [16], which provides in particular a way to extract the value of the difference of the pion scattering length $a_0^0 - a_2^0$, potentially more precise and direct than previously exploited methods such as studies of K_{e4} decays (see 5.1) or attempts to measure the lifetime of pionic atoms (DIRAC experiment).

Fig.17 reproduces the difference in the shape of the distribution, as shown in [16], neglecting or taking into account pion rescattering as described by the present PDG value for $a_0^0 - a_2^0$. The similarity with the experimental distribution is striking.

A quantitative fit for the precise evaluation of $a_0^0 - a_2^0$ requires a better simulation of the acceptance and efficiency of the detection system and, on the theoretical side, inclusion of smaller effects such as Coulomb and other strong rescattering correction. The full data set (including 2003-I and 2004 periods) is presently being processed and at first look at the shape shown in fig.16 is fully confirmed. It should be added that preliminary attempts at fitting the distribution also requires the inclusion of non negligible number of $\pi^0\pi^0$ events presumably originating from decays of the pionic atom.

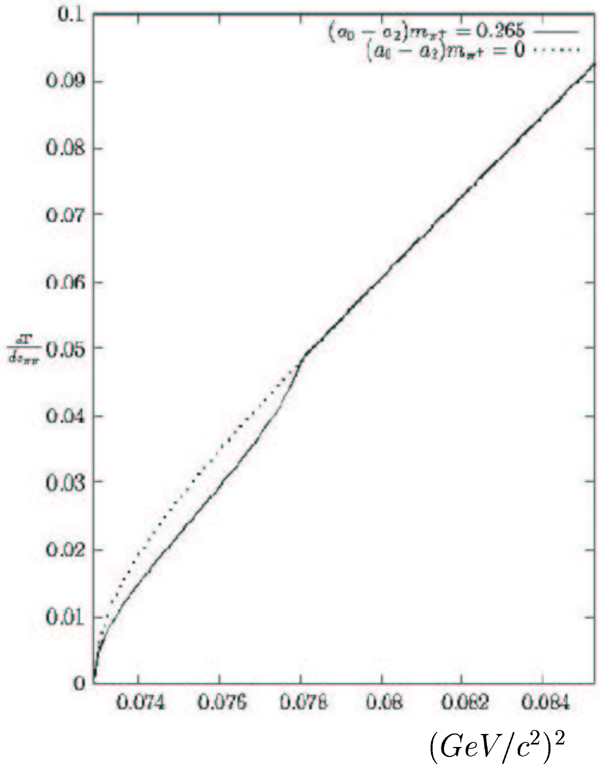

Fig. 17: Prediction of [16] model for the $M^2(\pi^0\pi^0)$ distribution in the region around the threshold, the dashed line indicate the spectrum simulated without the threshold effect.

7 Leptonic and Semileptonic decays

The main purpose of the study of semi-leptonic decays is to contribute to the measurements of the V_{us} matrix element of the Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix. At present V_{us} and V_{ud} are the most precisely known elements of the CKM matrix, with a fractional uncertainty at the level of $\sim 1\%$ and $\sim 0.1\%$, respectively. The present level of accuracy on $|V_{ud}|$ and $|V_{us}|$ is such that the contribution of $|V_{ub}|$ to the unitarity relation $U_{uu} = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$ can be safely neglected, and the uncertainty of the first two terms is comparable. Using the PDG data [14], an apparent violation of the unitarity relation is found above two sigma level.

The first result, based on $9 \cdot 10^4$ charged K_{e3} decays and $7 \cdot 10^5$ charged $K_{2\pi}$ decays used for normalization, has been obtained for the K_{e3} decay branching ratio:

$$Br(K^{\pm} \to \pi^0 e^{\pm} \nu) = (5.14 \pm 0.02_{stat} \pm 0.06_{syst})\%.$$

The analysis is based on data taken during an 8 hour dedicated run in 2003. The data was collected at low intensity and with a minimum-bias trigger in order to keep systematic uncertainties at a minimum. This result was already presented in the Beijing Conference (ICHEP-2004).

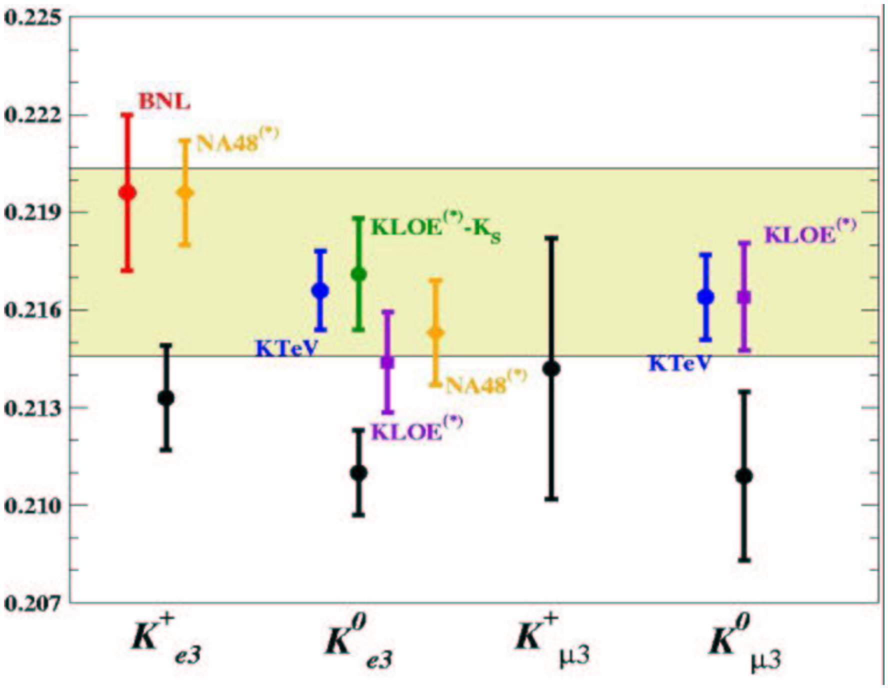

Fig. 18: Summary of $|V_{us}|$ results presented in ICHEP-2004.

Fig.18 shows the results of several groups which have started to face the challenge of the CKM unitarity problem. As one could see the NA48/2 result is already helping to clarify this puzzle. Our measurement is consistent with the recent results from the BNL-865 Collaboration [15] and with the SM, but disagrees with the current PDG values [14].

More then 4000 candidates to the $K^{\pm} \to e^{\pm}\nu$ decays and about $3.9 \cdot 10^6$ candidates to the $K^{\pm} \to \mu^{\pm}\nu$ decays (fig.19) have been selected in the analysis of a 56 hour special minimum-bias run carried out in 2004. The distributions of missing mass squared for these decays are presented in figs.19 (a) and (b), respectively. Clear peaks are seen in these plots around zero indicating an observation of K_{e2} and $K_{\mu2}$ decays with low background level.

Concerning leptonic and semi-leptonic decays, we expect the following analyses to be pursued:

- branching ratio and V_{us} measurement from charged K_{e3} decays;
- branching ratio and V_{us} measurement from charged $K_{\mu3}$ decays;
- test of lepton universality from $K_{e2}/K_{\mu2}$ decays;
- photon spectrum and branching ratio measurement from charged K_{e2}, $K_{\mu2}$, K_{e3} and $K_{\mu3}$ radiative decays;
- precise measurement of the K_{e3} form factors.

Strong motivations for all of these measurements were given at the Kaon Mini-workshop held at CERN in 2004 [18]. These analyses will be based mainly on the minimum-bias data sample taken in the special 56 hour run 2004. This sample has several million K_{e3} decays, to be compared to 90 thousand events from the 2003 data.

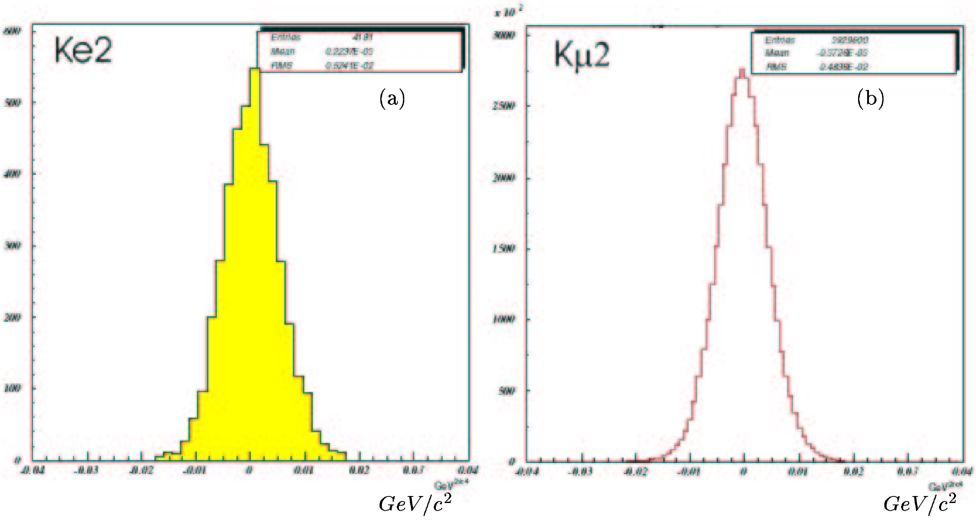

Fig. 19: Distribution of missing mass squared for $K^{\pm} \rightarrow e^{\pm}\nu_e$ *(a) and* $K^{\pm} \rightarrow \mu^{\pm}\nu_e$ *(b) decays.*

8 Plans on data processing

After the completion of accurate calibrations of all the detector elements the data accumulated in both runs 2003 and 2004 will be reprocessed. The reprocessing is planned to be done at CERN and the out put of each run requires $\sim$ 30 TB to be written on the CASTOR tapes.

A high statistics Monte Carlo simulation is foreseen to evaluate various acceptances and implement small corrections to the asymmetry calculations. An accurate tuning of the Geant-based Monte-Carlo for the NA48/2 running conditions was performed, to reflect time-variations of beam setting and check their effects. A first Monte-Carlo production was started. The MC simulation is planned to be done on the distributed computing resources in the collaborating Institutions. However the final MC data should be stored at CERN and will require around 5TB of space on CASTOR.

All these tasks require relevant resources to be allocated at CERN IT and in the collaborating Institutions.

9 Summary

The experiment NA48/2 has been prepared and carried out in 2003 and 2004. In total almost 110 days were available for data taking in relatively stable conditions. The corresponding statistics is useful for the measurement of the direct CP-violating asymmetry in charged kaon decays with minimum systematic uncertainties.

The first analysis of the data accumulated in 2003 run shows that the estimated statistical precision and systematic uncertainties of the measured asymmetry A_g are in agreement with those indicated in the proposal. The data accumulated in 2004 has a better quality for what concerns time stability and beam quality. The computing resources are required in 2005 for the successful completion of the data analysis and to obtain physical results.

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