Future NA48 programs for Hyperon rare decays and CP violation measurements

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June 27th, 2000
IV Int. Conf. on Hyperons, Charm and Beauty Hadrons

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Plan of the presentation

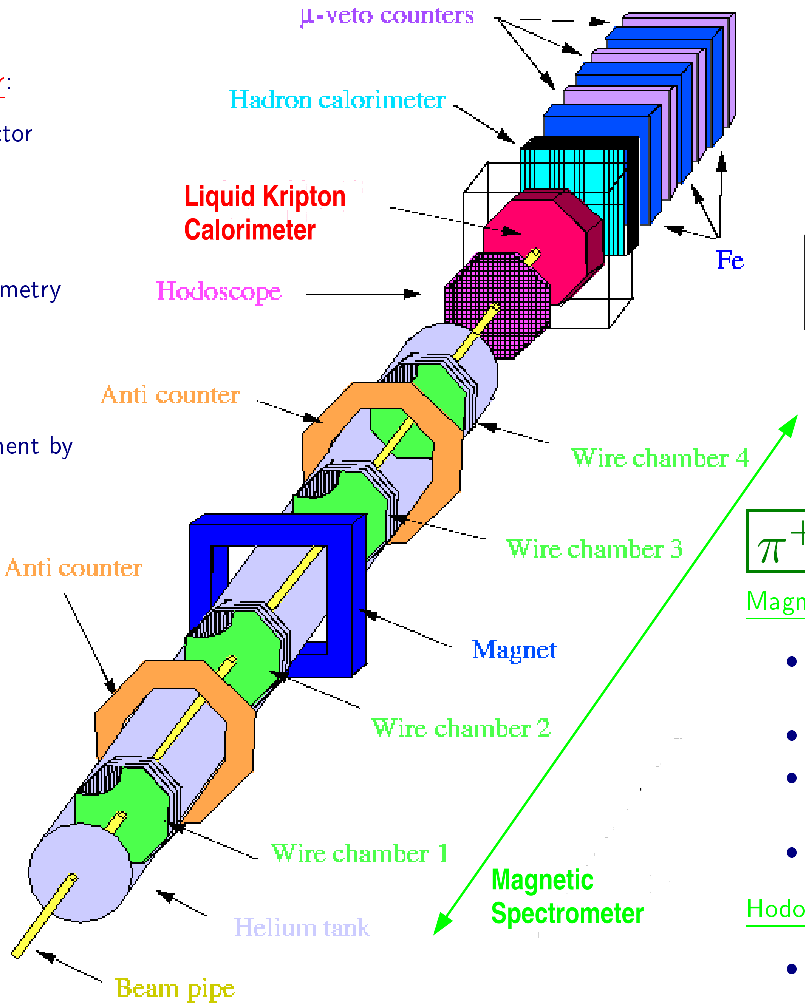
- Summary of non $\mathrm{Re}(\varepsilon'/\varepsilon)$ NA48 results
- Proposal for high intensity neutral hyperon and kaon decays studies
- Proposal for charged kaon physics
- Conclusions

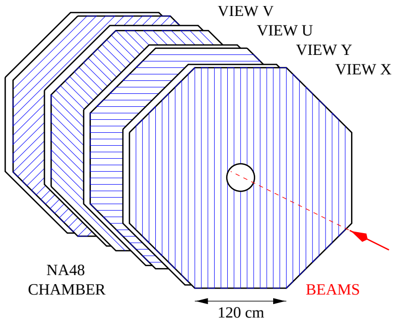
The Central Detector

$\pi^0\pi^0$

LKr electromagnetic calorimeter:

- quasi–homogeneous detector based on 9 m^3 LKr
- Cu–Be electrodes
- 13212 2 $\times$ 2 $\times$ 127 cm^3
- $\pm$ 48 mrad accordion geometry
- projective geometry
- geometry machined with 0.2 mm/m accuracy
- redundant time measurement by scintillating fiber neutral hodoscope





$\pi^+\pi^-$

Magnetic Spectrometer:

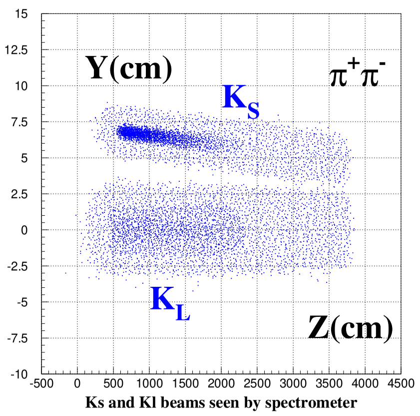
- 4 chambers with 4 views each, 2 staggered planes per view
- 90 μm spacepoint resolution
- wire position known better than 100 μm/m
- magnet providing 265 MeV/c p_T kick

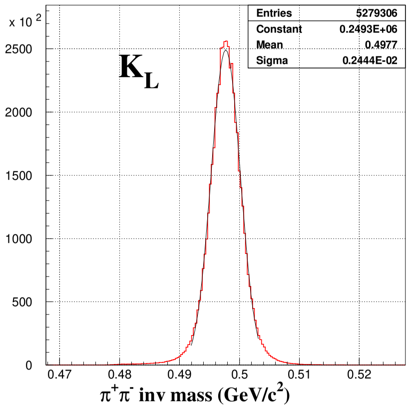
Hodoscope:

- 2 planes of scintillators for precise measurement of event time

Detector Performances

Magnetic spectrometer





$\sim$ 2 mm resolution on vertex transverse position (allows beam separation)

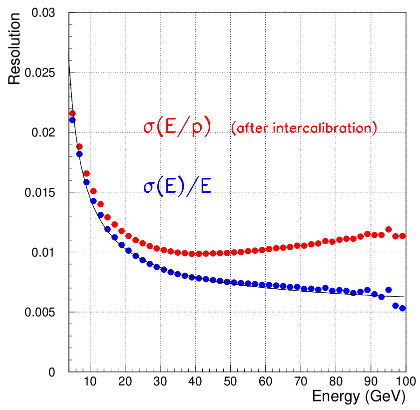
Kaon mass resolution $\sim$ 2.5 MeV/c^2

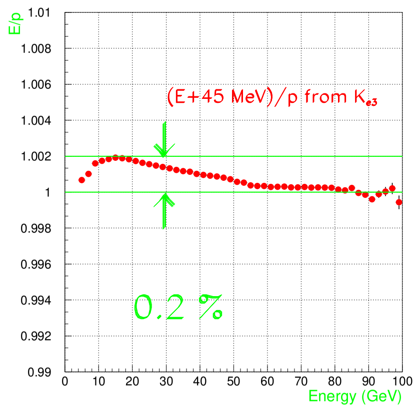
Momentum: $\sigma(P)/P \simeq 0.5\ \% \oplus 0.009\ P[\mathrm{GeV}/c]\ \%$

Charged Hodoscope

$<$ 200 ps time resolution for $\pi^+\pi^-$ event time

LKr calorimeter





Energy resolution:
$\frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{100\ MeV}{E} \oplus 0.5\%$
(E in GeV)

Non–Linearity <0.2% (from 5 to 100 GeV)

Time resolution for $\pi^0\pi^0$ event time: $<$ 250 ps

NA48 - Not only Re(ε'/ε)

In parallel to the Re(ε'/ε) analysis, there is a lot of activity going on using NA48 data, with results published or presented at many Conferences

- Neutral hyperon decay studies

  Best measurement of Ξ^0 mass

  Ξ^0 radiative decays

  $M(\Xi^-)$-$M(\Xi^0)$
- Λ^0 transverse polarization
- K_L and K_S rare decays

  $K_L \to \pi^0\gamma\gamma$

  $K_L \to \pi^+\pi^-e^+e^-$ T-violation asymmetry measurement

  $K_S \to \pi^+\pi^-e^+e^-$ First observation

  $K_S \to \pi^0e^+e^-$
- More channels under study

Starting point for the proposed future activity

Future programs

2 addenda to the NA48 proposal submitted to the SPSLC end of 1999

A high sensitivity investigation of K_S and neutral hyperon decays using a modified K_S beam

A precision measurement of charged kaon decay parameters with an extended NA48 setup

Referees recommended the physics program to the SPSLC in March 2000

The first program has been recommended by the SPSC in May

The second program will be considered by the Committee in the next session

Both experiments will be done after the end of the ϵ'/ϵ run as they imply modifications of the beam line

High Intensity K_S proposal

A short test has been done during 1999 run: the intensity of the NA48 K_S beam has been increased by a factor 160 with the K_L beam off.

$\rightarrow$ cleaner samples of rare K_S decays

$\rightarrow$ more statistics for the Hyperon channels

With minor optimization of the beam, an additional factor 2 can be achieved, reaching 400 times the standard K_S intensity in ϵ'/ϵ runs.

Expected SES for 1 year of data taking (120 days, 50% efficiency) is $3 \cdot 10^{-11}/\alpha$ where α is the acceptance for the decay after all cuts

For example, the decay $K_S \rightarrow \pi^0 e^+ e^-$ has a computed acceptance of 0.05, so SES = $6 \cdot 10^{-10}$, 500 times better than the actual limit

With a modest upgrade of the front-end electronics/readout systems, a factor 2 on the SES can be gained.

Physics case: $K_S \to \pi^0 e^+ e^-$

The interest in $K_S \to \pi^0 e^+ e^-$ is to bound the indirect CP violation in the $K_L \to \pi^0 e^+ e^-$ decay.

$K_L \to \pi^0 e^+ e^-$ is a place to look for direct CP violation. The current upper limit $BR(K_L \to \pi^0 e^+ e^-) < 5.64 \times 10^{-10}$ could be improved in the next few years by a factor of ≈ 2 by KTEV and more significantly by the KAMI (P804) proposal at FNAL.

The direct and indirect CP violating components interfere and the indirect contribution is linked to the parameter a_s (from ChPT). Since the a_s parameter cannot be predicted to any degree of confidence, a high sensitivity search for $K_S \to \pi^0 e^+ e^-$ is needed.

The Single Event Sensitivity for 1 year is 6×10^{-10}.

It corresponds to 7 events for $BR(K_S \to \pi^0 e^+ e^-) = 5 \times 10^{-9}$.

The study of the backgrounds is well advanced and the main limitation is now Montecarlo statistics.

Physics case: CP violation in $K_S \to \pi^0\pi^0\pi^0$

$|K_S> \simeq |K_1> + \epsilon_S |K_2>$

$CP(|K_1>) = +1 \quad CP(|K_2>) = -1 \quad CP(\pi^0\pi^0\pi^0) = -1$

CP-violation in the K_S decay: $\eta_{000} = \frac{A(K_S \to \pi^0\pi^0\pi^0)}{A(K_L \to \pi^0\pi^0\pi^0)}$

Experiment	$\mathfrak{Re}(\eta_{000})$	$\mathfrak{Im}(\eta_{000})$	$BR(K_S \to \pi^0\pi^0\pi^0)$
Barmin et. al	-0.08 ± 0.27	-0.05 ± 0.27	$< 3.7 \times 10^{-5}$ 90 % CL
CPLEAR	0.18 ± 0.15	0.15 ± 0.20	$< 1.9 \times 10^{-5}$ 90% CL
SND			$< 1.4 \times 10^{-5}$ 95% CL

$\mathfrak{Re}(\eta_{000}) = \mathfrak{Re}(\epsilon) \sim 1.6 \times 10^{-3}$ is predicted by the CP violation in the K^0 -$\overline{K}^0$ mixing and the imaginary part is sensitive to direct CP violation in a decay amplitude. This proposal aims to reduce the error on $\mathfrak{Re}(\eta_{000})$ and $\mathfrak{Im}(\eta_{000})$ by a factor of 10, measuring $K_S - K_L$ interference near the production target.

Neutral hyperon decays

The high intensity K_S beam will be used to improve our current results on neutral hyperon decays, as well as to start new studies.

- Improve the error on $M(\Xi^-) - M(\Xi^0)$ to 0.1 Mev/c^2 ($\times 2.5$)
- Improve by a factor 2 the systematic error on Ξ^0 radiative decays and get at least a global 5% uncertainty
- Hyperon β decays
  The β decay of the Ξ^0 hyperon ($\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}$), with a branching ratio of 2.5×10^{-4}, can be detected in NA48 by identifying the electron in the LKr calorimeter and the Σ^+ by its decay to pπ^0 (51%). We expect to collect up to 25000 events to check the SU(3) symmetry and the Cabibbo model in hyperon decays.
- Search for $\boldsymbol{\Xi^0 \longrightarrow p\pi^-}$
  The present experimental limit on this decay with a double strangeness change (ΔS = 2) is $\leq 4\times10^{-5}$ at 90% CL. We plan to improve this limit by a factor of at least 500.
- Start looking into $\boldsymbol{\Sigma}$ physics (from $\boldsymbol{\Xi^0 \rightarrow \Sigma^0\gamma}$)

Competition

- K_S
  - The competition to this experiment comes from the KLOE detector. However, even at the full DAΦNE design luminosity of $5\times\ 10^{32}$ cm^{-2}s^{-1}, the sensitivity per annum for $K_S \rightarrow \pi^0 e^+ e^-$ is less than this proposal.
  - Unlike KLOE, we cannot tag our K_S , thus making the two experiments complementary.

- Neutral hyperons
  - The competition comes from the KTEV experiment which collects neutral hyperons from the vacuum beam. Only hyperons with very high energy decay in the fiducial region. This loss is offset in part by the capability to track the leading baryon in the beam (no hole in tracking chambers).
  - Overall this proposal is up to one order of magnitude better than KTEV

K_S beam parameters

Beam	$K_L + K_S$ (Re(ε'/ε))		Intense K_S beam	
Year	1999		Phase I	Phase II
SPS momentum (GeV/c)	450		450	400
Duty Cycle (s/s)	2.5/14.4		2.5/14.4	5.0/19.2
Protons per pulse on target	1.5×10^{12}	3×10^{7}	5×10^{9}	1×10^{10}
Production angle α (mrad)	+2.4	-4.2	-4.2	-2.5
Total beam flux K's/pulse	$\sim 2\times10^{7} + \sim 3\times10^{2}$		$\sim 5\times10^{4}$	$\sim 1.5\times10^{5}$
K-decays in Δp_K /pulse	$1.0\times10^{5} + 1.8\times10^{2}$		4.0×10^{4}	1.1×10^{5}
K-decays in Δp_K /year (0.5 × 120 days)	$3.6\times10^{10} + 6.5\times10^{7}$		1.4×10^{10}	3.0×10^{10}

Schedule of the program

During the year 2000, NA48 cannot complete the $Re(\varepsilon'/\varepsilon)$ program because of the vacuum accident which destroyed the wires of the 4 drift chambers (November 1999). The activity for this year is concentrated on special runs to improve the systematics in the neutral sector and to start the high intensity K_S program.

- Phase 1 (Year 2000):

  We will have 50 days of protons at 400 GeV/c with an increased duty cycle to get started with the K_S neutral decays, notably $K_S \to \gamma\gamma$ and η_{000}.

  - No drift chambers, no beam-pipe and no kevlar window
  - Extend the vacuum into the Helium tank

- Phase 2 (Year 2002, after completion of $Re(\varepsilon'/\varepsilon)$ in 2001):

  120 days of 400 GeV/c protons with the best possible duty cycle to finish off the neutral K_S decays and achieve the proposed sensitivities for hyperon physics and for the rest of the K_S programme, notably $K_S \to \pi^0 e^+ e^-$.

Charged kaon physics

We propose to study with high statistics specific properties of the decay of charged kaons:

- Direct CP violation in $K \rightarrow 3\pi$
- $q\bar{q}$ condensate in QCD vacuum (K_{e4})
- Detection of possible deviations from V-A and from the Standard Model
- Measurement of rare charged kaon decays involving photons and/or e^+e^- pairs

Use new simultaneous charged kaon beams

Upgrade NA48 detector with a TRD for π/e rejection (K_{e4}) and with a small beam spectrometer.

Request one full year of SPS beam

Direct CP Violation in $K^{\pm}$ decays

The latest measurements of $\mathrm{Re}(\varepsilon'/\varepsilon)$ are higher than the average theoretical predictions.

It is useful to have an independent measure of direct CP violation, without the complications induced by mixing as in neutral kaons.

Any difference between K^{+} and K^{-} decays is an evidence for direct CP violation, coming from the definition itself.

Author	A_g prediction
A. Belkov et al.	$(2\text{-}4)\cdot 10^{-4}$
E. Shabalin	$4\cdot 10^{-4}$
D'Ambrosio	$4\cdot 10^{-5}$
L.Maiani, N.Paver	$(2.3 \pm 0.6) \cdot 10^{-6}$
D'Ambrosio et al.	$\approx 10^{-4}$

Principle of the measurement

Direct CP violation induces an asymmetry in the Dalitz plot density of the decays $\mathrm{K}^\pm \to \pi^\pm\pi^+\pi^-$ and $\mathrm{K}^\pm \to \pi^\pm\pi^0\pi^0$

The decay matrix element is parametrized as

$$|\mathrm{M(u,v)}|^2 \propto 1 + \mathrm{g{\cdot}u} + \mathrm{h{\cdot}u^2} + \mathrm{k{\cdot}v^2}$$

where $u = (s_3 - s_0)/m_\pi^2, v = (s_1 - s_2)/m_\pi^2, s_0 = (s_1 + s_2 + s_3)/3, s_i = (P_K - P_i)^2$ and i=3 is the odd pion.

The asymmetry of the Dalitz plot density is defined as

$$A_g = \frac{g^+ - g^-}{g^+ + g^-}$$

Measure the ratio

$$R(u) = \frac{\int dv |M^+(u,v)|^2}{\int dv |M^-(u,v)|^2} \approx 1 + u \cdot (g^+ - g^-)$$

A slope as a function of u is a measure of direct CP violation.

Principle of the measurement, ctnd.

Care must be taken to minimize the systematics which can create a slope different from zero, especially differential effects between opposite polarities

Simulations done to look for induced A_g with

- Different spectra of K^+ and K^-
- Local inefficiencies in drift chambers
- Differences between the magnetic field in the two polarities
- Relative offset of the two beams
- Relative asymmetry in the profile of the two beams
- Differences in the punch-trough probabilities for positive and negative pions
- Difference in the interaction probability in the spectrometer for positive and negative pions

Those systematics could be kept at a level of less than 10^{-4} in the following conditions:

- Use simultaneous K^+ and K^- beams
- Maximize the overlap of the two beams using correcting dipoles
- Alternate the sign of the spectrometer field
- Bin in P_K and in u
- Do offline circular acceptance cuts centered on the center of gravity of the two beams

Study of $K^{\pm} \rightarrow \pi^{+}\pi^{-}e^{\pm}\nu$

This decay allows to verify the dependence of the pion mass from the strong $q\bar{q}$ condensate in the QCD vacuum within the framework of Chiral Perturbation theory.

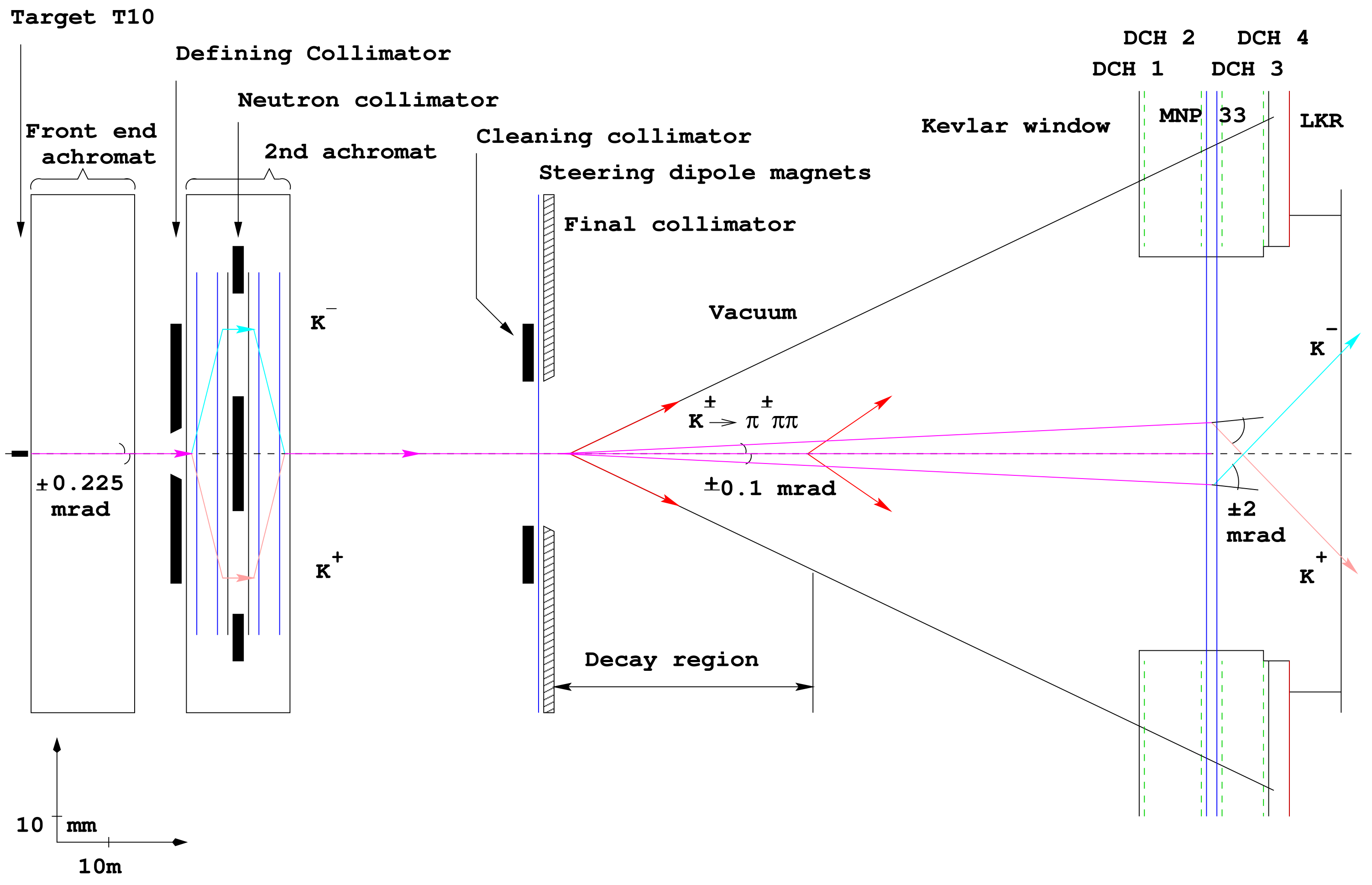
No experimental confirmation up to now for $q\bar{q}$ condensate

The most important parameter is a_0^0, the S-wave scattering length

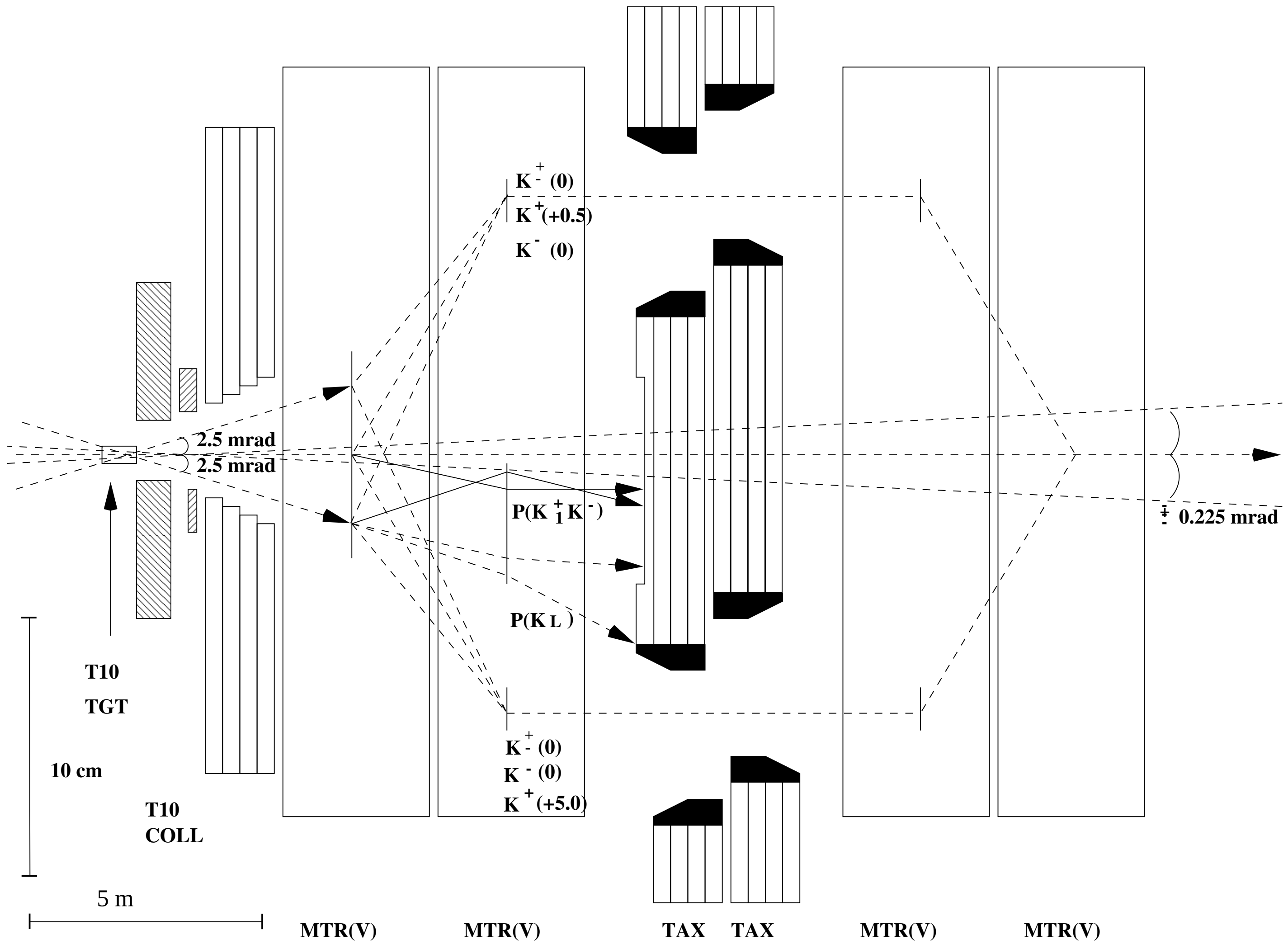
Previous results and expectations:

Experiments	Statistics	$a_0^0 \pm \delta a_0^0$
Geneva-Saclay 1977	3.0×10^4	0.26 ± 0.05
BNL865 (data recorded)	0.4×10^6	$\approx \pm\ 0.015$
KLOE (1 year)	0.3×10^6	$\approx \pm\ 0.015$
NA48 (1 year)	1.0×10^6	$< \pm\ 0.010$

Simultaneous K^+ and K^- beams



Simultaneous K^+ and K^- beams



The first acromat

Estimated uncertanties on A_g

Source	Uncertainty on $A_g (10^{-5})$
Beam non collinearity	< 3.8
Momentum binning	< 1.0
Resolution on u	0.1
Difference B↑-B↓	< 5.0
B correlated inefficiencies in DCH	< 3.0
Accidentals	< 2.5
$\pi^+ - \pi^-$ cross section difference	< 0.07
Pion punch-through effects	< 0.5
Total	< 7.5

Experiment	Decays	Statistics	δA_g
HyperCP (completed)	$K^\pm \rightarrow \pi^\pm\pi^+\pi^-$	1.6×10^8	$\approx 7 \times 10^{-4}$
KLOE (1 year)	$K^\pm \rightarrow \pi^\pm\pi^+\pi^-$	1.5×10^8	$\approx 4.4 \times 10^{-4}$
	$K^\pm \rightarrow \pi^\pm\pi^0\pi^0$	0.6×10^8	$\approx 6.3 \times 10^{-4}$
NA48 (1 year)	$K^\pm \rightarrow \pi^\pm\pi^+\pi^-$	2.0×10^9	$\approx 1.7 \times 10^{-4}$
	$K^\pm \rightarrow \pi^\pm\pi^0\pi^0$	1.2×10^8	$\approx 3.1 \times 10^{-4}$

Upgrade of the detector

Upgrade the detector with a TRD to improve electron identification (for K_e4 decays)

π/e rejection >100 at ϵ_e=90%, 1<P<50 Gev/c

Use 7 modules of the NOMAD TRD in front of the LKr Calorimeter

Each module has a 315 plastic foil radiator, 176 straw tubes and it is filled with a Xe/CH_4 mixture

Need some modifications to open a beam hole

Study under way to integrate the TRD readout in the NA48 DAQ

Simulation of this TRD in the NA48 environment shows that for $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$, i.e. the main background to K_e4, the rejection factor is 345 at ϵ_e=90% and 111 at ϵ_e=95%

Upgrade of the detector, ctnd.

To get a good measurement of the parent kaon momentum, it is planned to add a beam spectrometer in the path inside the second achromat

Use time coincidence to associate the kaon with the event and the position measurement in the vertical plane to measure the kaon momentum and its direction

This will resolve the ambiguity in the kinematic fit of the K_{e4} decay

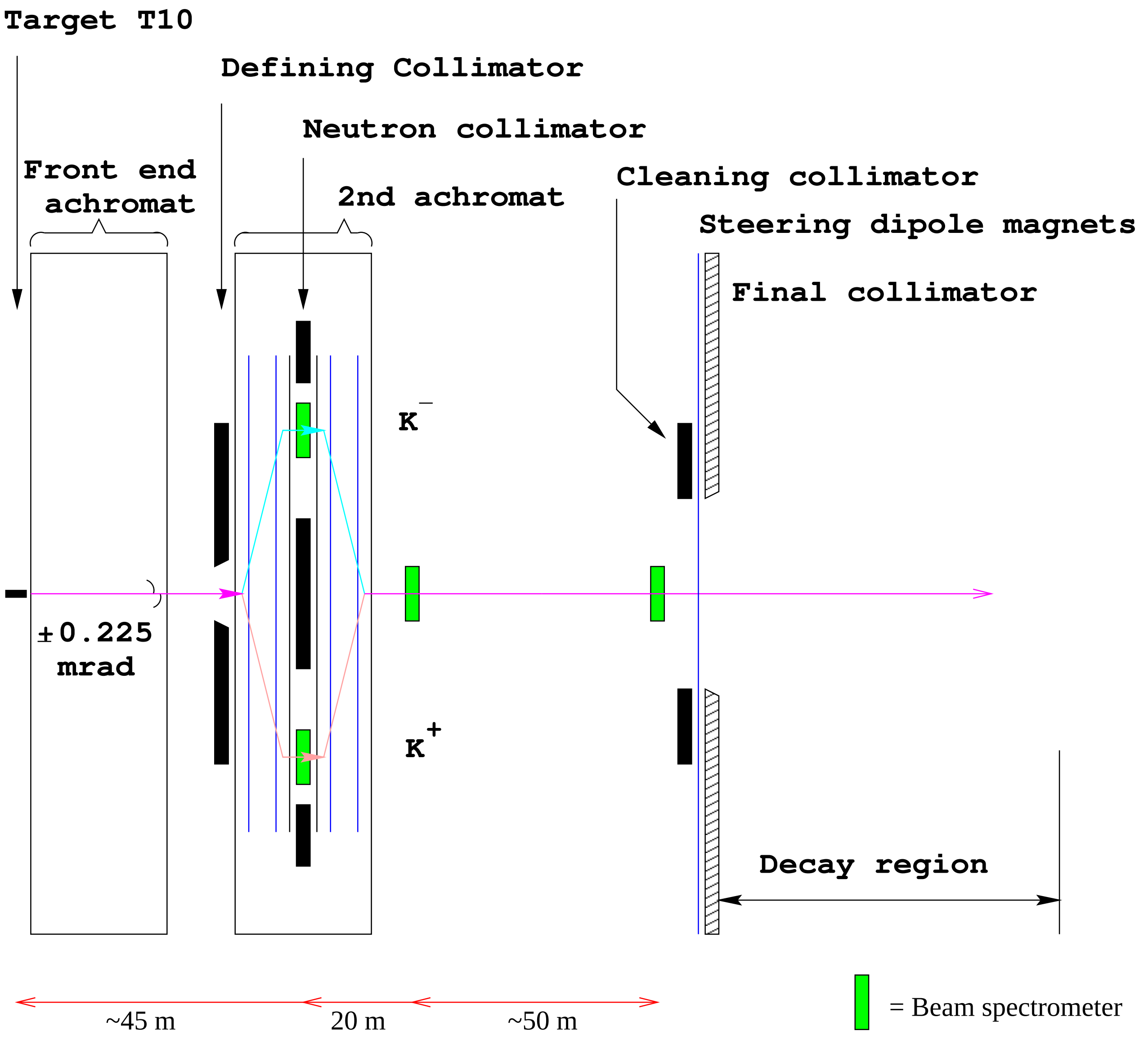
Need for:

- High rate capability ($\approx 4 \times 10^7$ part/s)
- $\delta p/p \leq 1\%$
- $\sigma_{\theta x}, \sigma_{\theta y} \leq 1.5 \times 10^{-2}$
- Minimum material along the beam ($\leq 10^{-3} X_0$)

Use a Micromegas like detector, with strips along the beam and drift orthogonal to the beam

First simulations show possible time resolution of better than 1 ns, momentum resolution of 1% and angular resolution of better than 10^{-2}, with the recommended value for X_0.

The beam spectrometer



Positioning of the beam spectrometer

Conclusions

The NA48 collaboration has submitted two proposals for further running after the end of $\mathrm{Re}(\varepsilon'/\varepsilon)$ program.

The first one will use the actual beam line and detector with almost no upgrade to study $\mathrm{K_S}$ and neutral hyperon decays with a beam intensity 400 times the actual one.

The second will make use of simultaneous charged kaon beams to study direct CP violation in the decay $\mathrm{K}^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ and the structure of the $q\bar{q}$ condensate in the decay $\mathrm{K}^{\pm} \rightarrow \pi^{+}\pi^{-}\mathrm{e}^{\pm}\nu$.

The first proposal has been recommended, the second is still under evaluation.

The proposed physics program will be performed after the end of the $\mathrm{Re}(\varepsilon'/\varepsilon)$ program.