Measurement of Direct CP Violation in Charged Kaons Decays by the NA48 Experiment in 2003

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- Physics Motivation
- NA48 Method
- Beams and Detector
- Expected Uncertainties
- Conclusions

On behalf of the NA48/II Collaboration

Direct CP violation in K^o decays

Precise studies of direct CP violation
in different channels of K decays
powerful tool
to constrain CKM parameters
to search for new physics

Direct CP violation in K^o decays:

$$K_L = K_2{}^{CP=-1} + \varepsilon K_1{}^{CP=+1}$$

$$\underbrace{\pi^+\pi^-, \pi^o\pi^o}_{\mathrm{CP}=+1}$$

Two pion state from K^o can have I=0 or I=2
decay through TWO INTERFERING AMPLITUDES
A_0 $(\Delta I = 1/2)$ and A_2 $(\Delta I = 3/2)$
with different weak and strong phases

→ CP violation in the decay

$$|A(K^o \to (2\pi)\ )| \neq |A(\overline{K^o} \to \overline{(2\pi)}\ )|$$

Direct CP violation firmly established
(KTeV, NA48) in K^o decays:

$$\frac{\Gamma(K^o \to \pi^+\pi^-) - \Gamma(\overline{K^o} \to \pi^+\pi^-)}{\Gamma(K^o \to \pi^+\pi^-) + \Gamma(\overline{K^o} \to \pi^+\pi^-)} = (4.8 \pm 0.7) \times 10^{-6}$$

(NA48 final result)

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

Direct CP violation is expected to produce different amplitudes

$$|A(K^+ \to (3\pi)^+)| \neq |A(K^- \to (3\pi)^-)|$$

Parametriz. $A(K \to 3\pi) = a + b \cdot u + O(u^2, v^2)$

$u = (s_3 - s_0)/m_\pi^2$, $v = (s_1 - s_2)/m_\pi^2$ → Dalitz var.

a and b → TWO $\Delta I = 1/2$ INTERFERING AMPLITUDES

with different strong and weak phases

Observable matrix elements:

$$|M(u,v)|^2 = 1 + g \cdot u + O(u^2, v^2)$$

slope param. g sensitive to interference of a and b

⟹ Direct CP violation induces different probability distributions of the final state momenta configuration for K^+ and K^- decays

⟹ Observable asymmetry:

$$\boxed{A_g = \frac{g^+ - g^-}{g^+ + g^-} \neq 0}$$

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

Expectations for A_g:

$K^{\pm} \rightarrow \pi^{\pm}\pi^{-}\pi^{+}$ decay

SM predictions: $A_g \sim$ few 10^{-5}

Beyond SM: A_g up to few 10^{-4}

$K^{\pm} \rightarrow \pi^{\pm}\pi^{o}\pi^{o}$ decay

$A_{g'} \approx A_g$ in case $\Delta I = 3/2$ transitions are suppressed

Measurement of A_g :

$A_g = (-7 \pm 5) \cdot 10^{-3}$ in $\mathrm{K}^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm}$ decay

(Ford et al. 1970)

Measurements of linear slope parameters:

	$\mathrm{K}^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm}$	$\mathrm{K}^{\pm} \rightarrow \pi^{o}\pi^{o}\pi^{\pm}$
g^{+}	-0.2154 ± 0.0035	0.672 ± 0.030
g^{-}	-0.2170 ± 0.0070	0.642 ± 0.057
	(PDG)	(PDG + hep-ex/0205027)

NA48 method

Count the decays in the two modes $K^{\pm} \to \pi^+\pi^-\pi^{\pm}$
measure the ratio $R(u) = \frac{N^+(u)}{N^-(u)}$
as a function of the Dalitz variable u

If acceptances equal for the two modes:

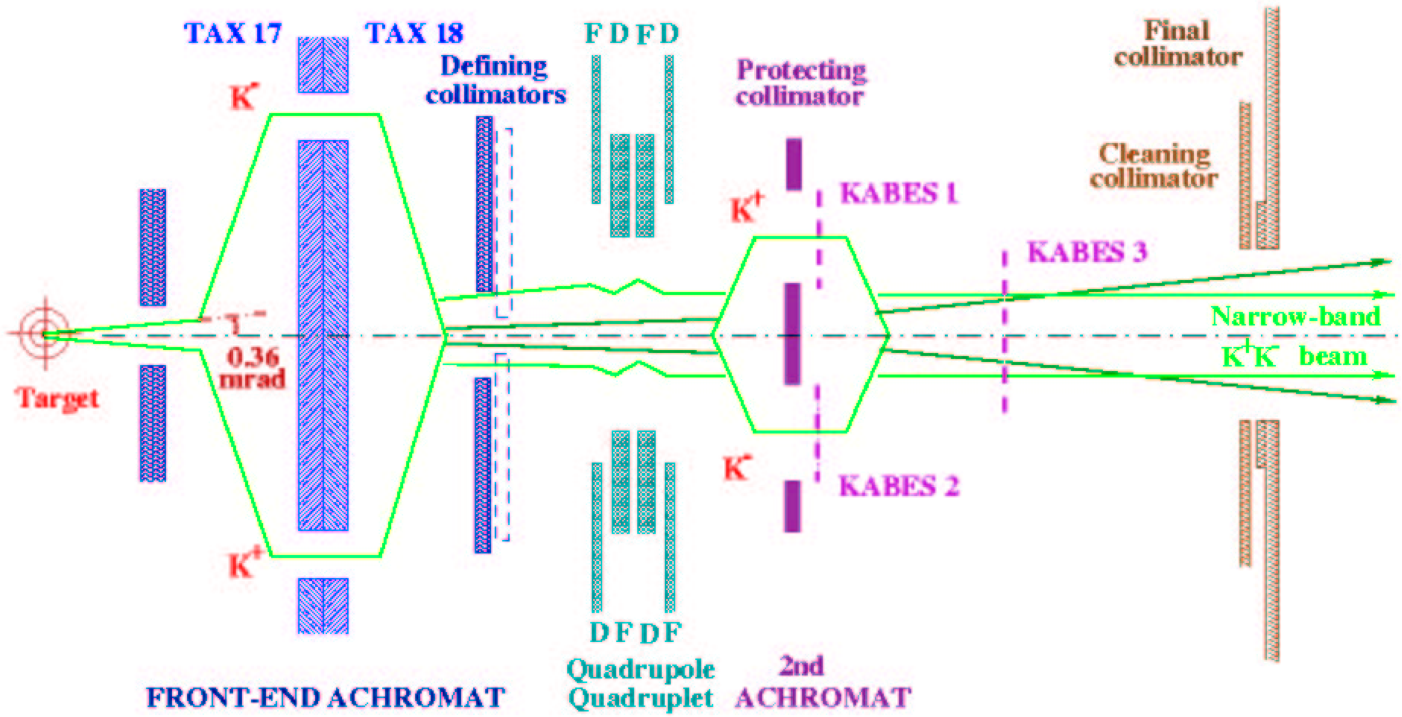
$$R(u) \propto \frac{1+g^+u+O(u^2)}{1+g^-u+O(u^2)} \propto 1 + (g^+ - g^-) \cdot u$$

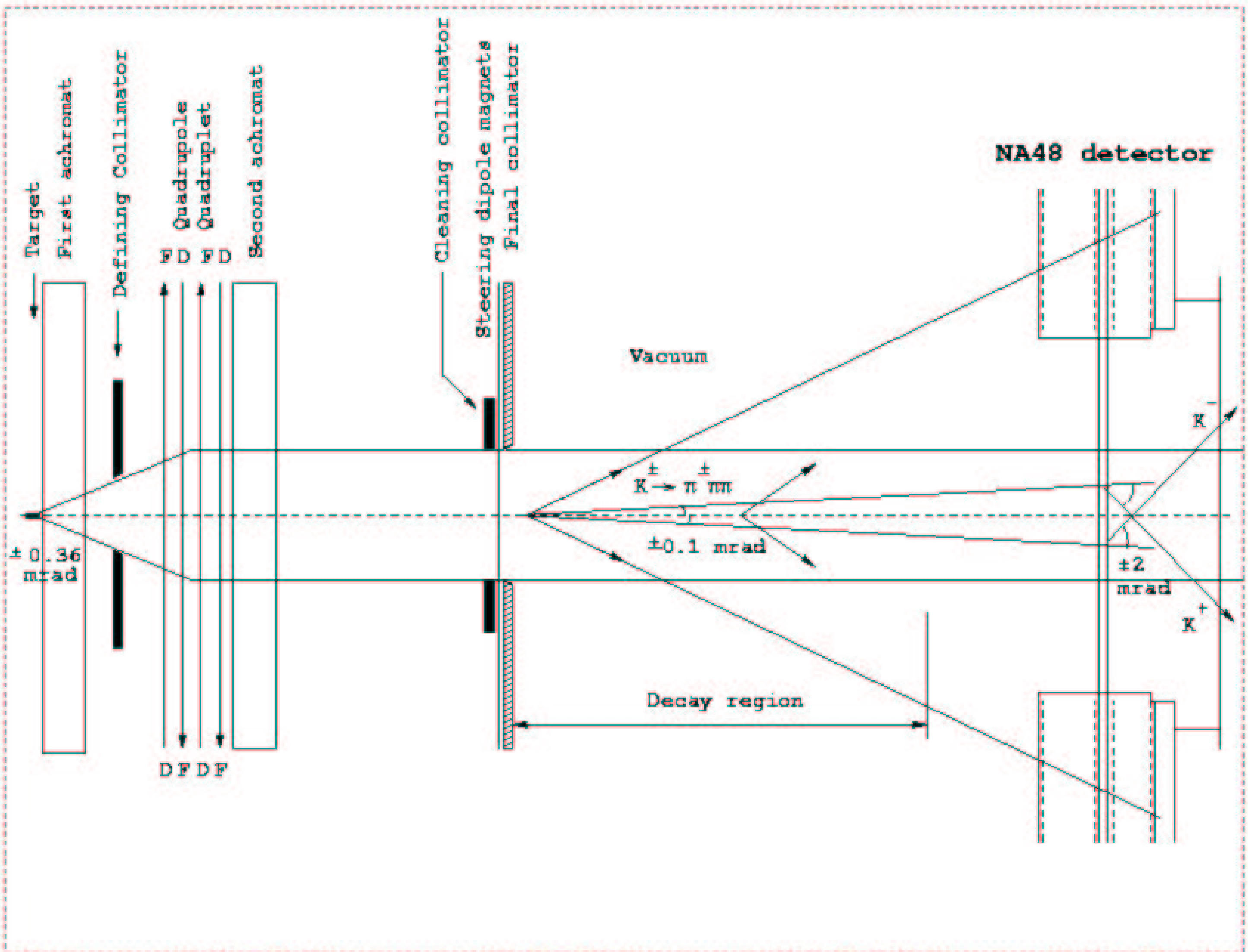
Slope of $R(u)$ $\Longrightarrow$ $A_g \neq 0$

NA48 method

- Two simultaneous focused K^+ and K^- beams overlapping in space and time with narrow band momentum $(p_K = 60 \pm 3GeV/c)$
- Detect asymmetry exclusively with ratio of distributions for K^+ and K^- and in bins of kaon momentum p_K
- Equalize K^+ and K^- Acceptances by running with both polarities for the spectrometer magnet regularly alternated

Simultaneous K^+ and K^- beams



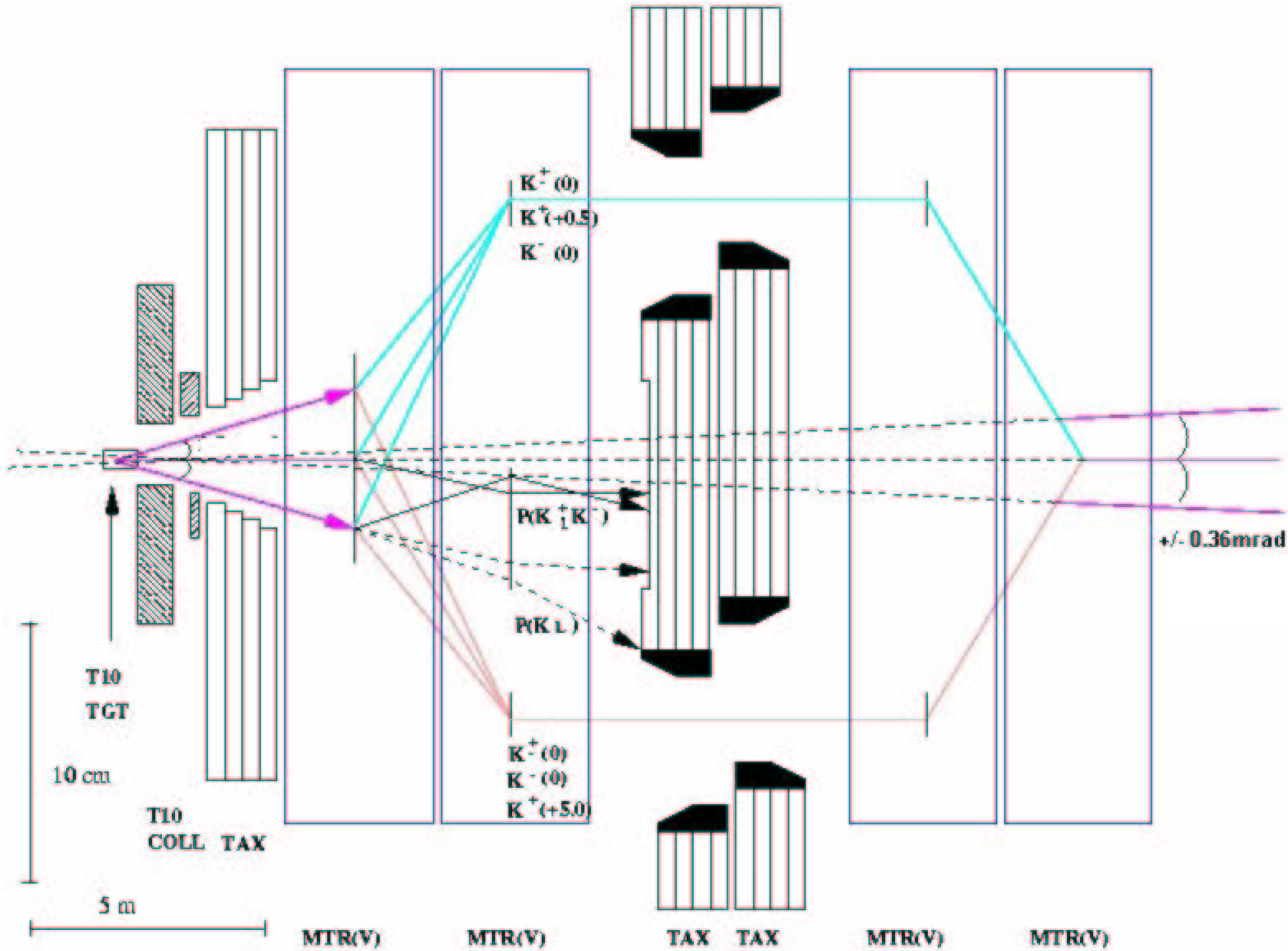


Target
First achromat
Defining Collimator
Quadrupole
Quadruplet
Second achromat
F D F D
D F D F
Cleaning collimator
Steering dipole magnets
Final collimator
NA48 detector
Vacuum
$K^{\pm} \to \pi^{\pm} \pi\pi$
±0.36 mrad
±0.1 mrad
±2 mrad
K^-
K^+
Decay region

Simultaneous K^+ and K^- beams

Beam	K^+		K^-
Primary proton momentum (GeV/c)		400	
Duty cycle (s/s)		$5.2/16.8$	
P.o.t. per cycle		10^{12}	
Production angle (mrad)		0^o	
Beam Acceptance (mrad)		± 0.36	
Beam Momentum (GeV/c)		60 ± 3	
Target to final coll. (m)		102	
$p/\bar{p}$ per cycle (10^6)	8.6		0.9
π^+/π^- per cycle (10^6)	33.2		24.6
K^+/K^- per cycle (10^6)	3.1		1.8
Fiducial Region from target (m)		$107 < z < 207$	
$K^\pm \to (3\pi)^\pm$ per year (10^{10})	1.4		0.8

First Acromat



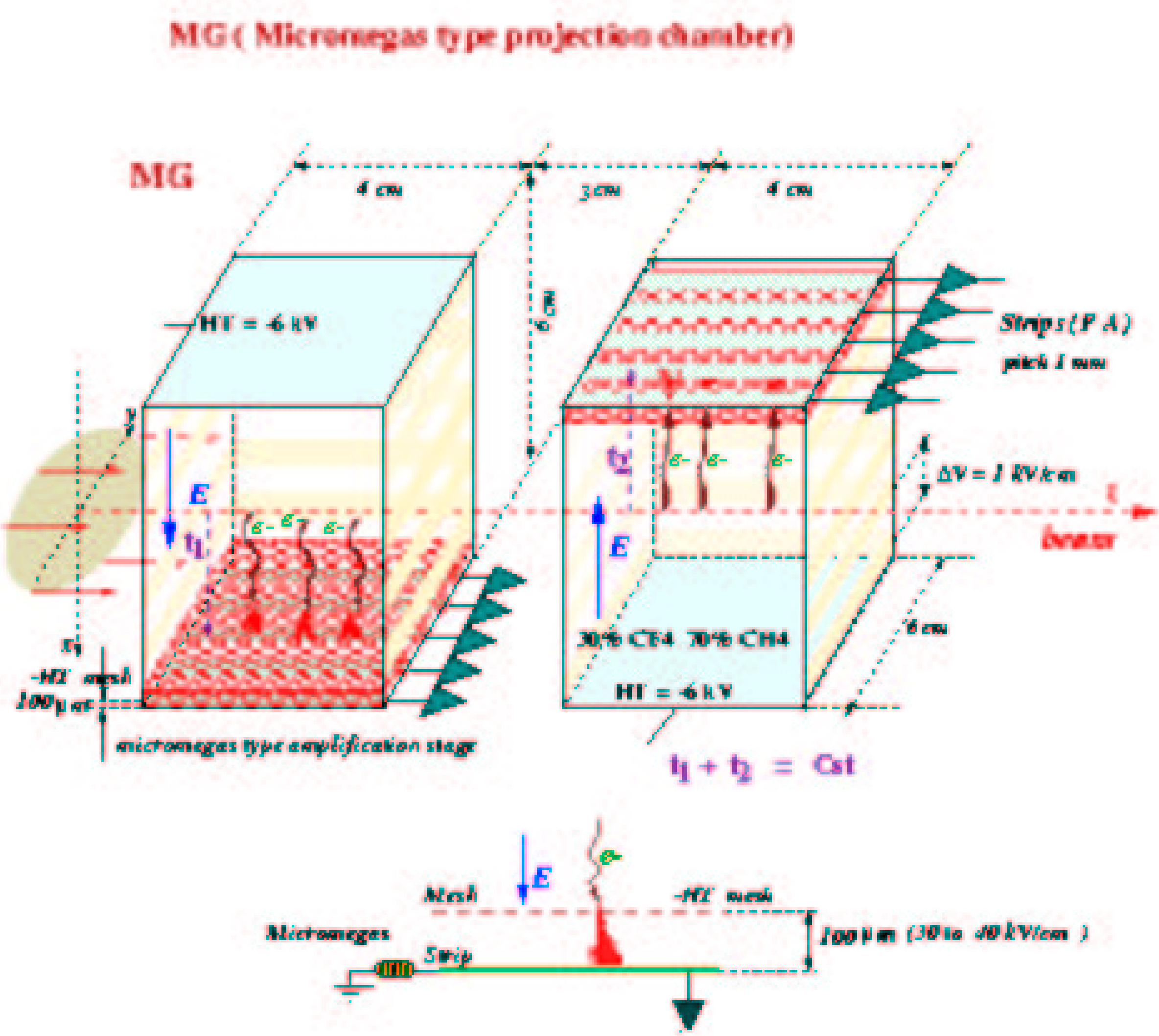
KAon BEam Spectrometer

"Individual" Kaon Measurement
by 3 double stations of
projection chambers
MicrOmega type amplification stages
placed in 2nd Acromat

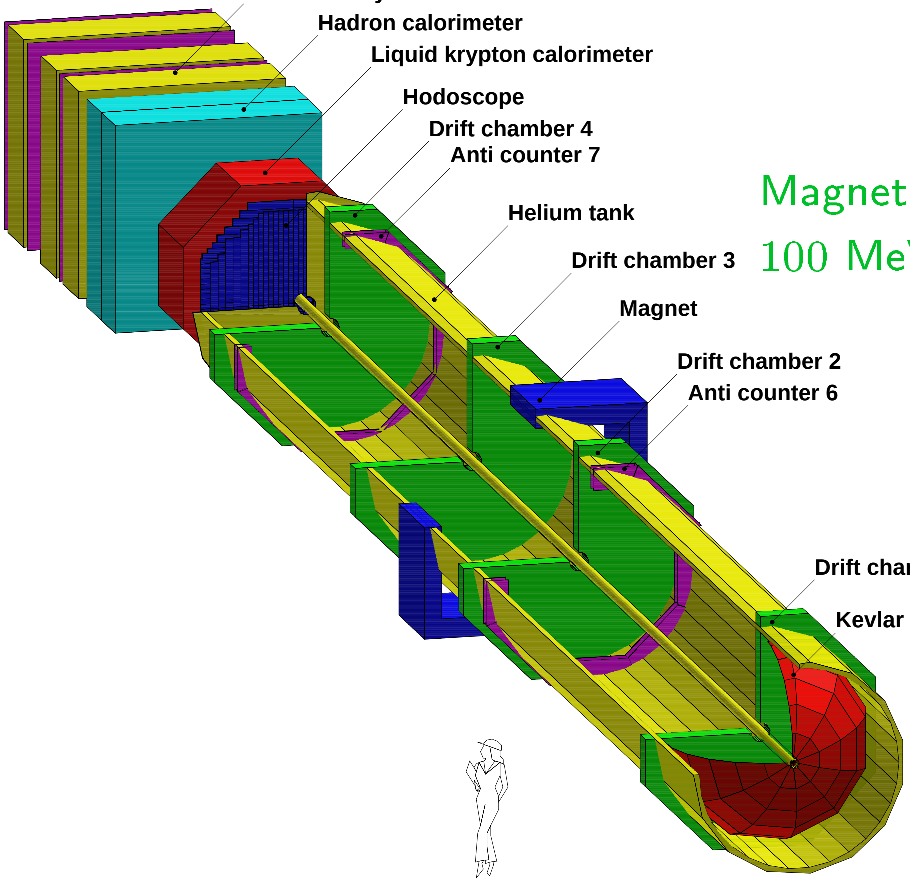
Measure TIME and VERTICAL POSITION of each $K^{\pm}$
⟹ kaon TAGGING with TOF
⟹ measurement of kaon MOMENTUM and CHARGE

- high rate capability (up to 40 MHz)
- $\delta p/p < 1\%$
- $\sigma_t < 1$ ns
- $\sigma_{\theta_{x,y}} < 10$ mrad
- material $< 10^{-3} X_o$

KABES


MG (Micromegas type projection chamber)
MG
4 cm
3 cm
4 cm
6 cm
HT = -6 kV
Strips (F A)
pitch 1 mm
E
t1
t2
e-
ΔV = 1 kV/cm
beam
30% CF4 70% CH4
HT = -6 kV
6 cm
-HT mesh
100μm
micromegas type amplification stage
t1 + t2 = Cst
E
Mesh
-HT mesh
Micromegas
Strip
100 μm (30 to 40 kV/cm)

NA48 Central Detector



Magnet p_T Kick
100 MeV/c

- MAGNETIC SPECTROMETER

→ Redundancy → High Efficiency

→ High Resolution

- HODOSCOPE

→ Fast & High Granularity Multplicity Trigger

→ Precise Time Meas. $(\sigma_t \sim 150\,ps)$

- MUON VETO → Off-line Rejection of μ Background.
- LIQUID KRYPTON ELECTROMAGNETIC CALORIMETER :

→ Quasi-Homogeneous & High Granularity

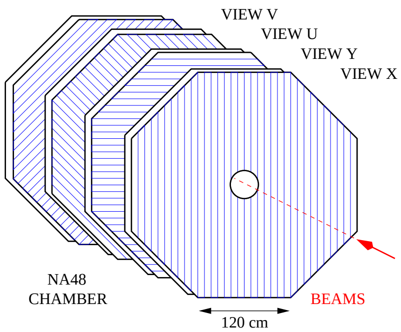
→ Trigger with no dead-time

→ Precise Time Meas. $(\sigma_t \sim 220\,ps)$

→ High E Resol. $(\sigma_E/E \sim 1\%$ for 20 GeV photon)

→ Powerful e/π discrimin. $(1 : 10^4)$

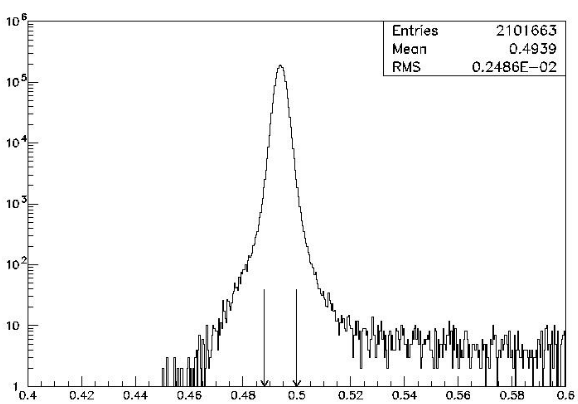
Magnetic spectrometer



Per Chamber:

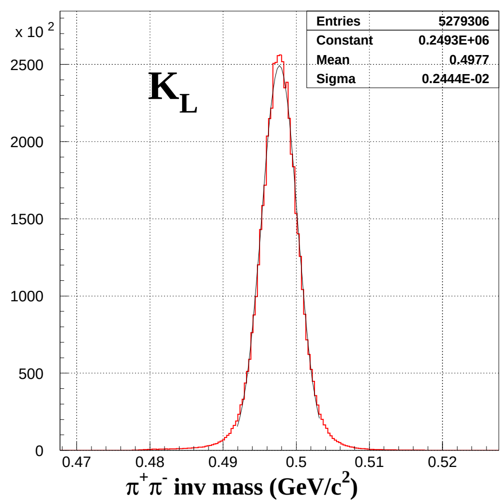
- 8 planes of 256 wires
- $\sigma_{X,Y} \sim 90\ \mu$m
- NEW DCH Read-Out
  High Hit Rate Capab.
  $\Rightarrow$ NO Dead-Time

$K^{\pm} \rightarrow \pi^+\pi^-\pi^{\pm}$



Kaon mass resolution
$\sim$ 1.5 MeV/c^2

$K_L \rightarrow \pi^+\pi^-$



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

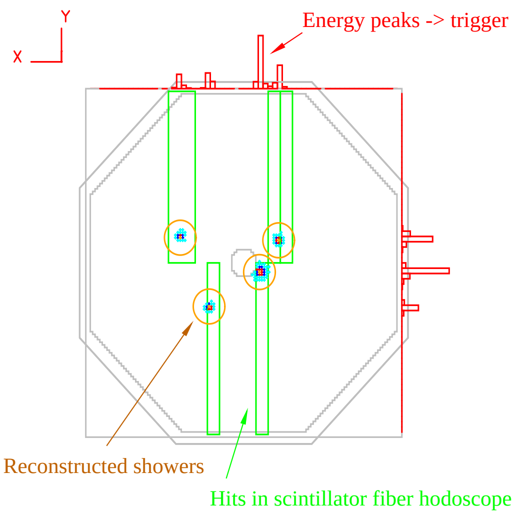
$$\sigma(p)/p \simeq 0.5\ \% \oplus 0.009\ p\ [\text{GeV/c}]\ \%$$

$\approx$ 0.5 % for 20 GeV/c track momentum

Trigger

Neutral

- Input rate capability: up to few MHz
- Fully pipelined system using LKr cell information summed to horizontal and vertical projections to compute energy, centre of gravity, π^o vertices position and number of showers
- Latency 5μs
- Negligible Dead Time



Charged

- Level 1 : Fast Trigger
  - Input rate capability: up to few MHz
  - Track multiplicity in hodoscope
  - Track multiplicity in DCH (opt.)
  - Energy in calorimeter (opt.)
  - ANTI-counters and μ-VETO (opt.)
- Level 2 : On-line Processing of tracks
  - Input rate capability: 200 KHz
  - Latency $< 100\ \mu s$
  - Small Dead Time $< 0.1\%$ with the NEW DCH READ-OUT

Expected Rates

Source	Rates (KHz)
$\pi^+ \to \mu^+\nu$	250
$\pi^- \to \mu^-\nu$	150
$K^+ \to$ all	110
$K^- \to$ all	60
trigger L1 charged (Hodoscope Multiplicity ≥ 2)	120
trigger L1 neutral (LKr Peak Multiplicity ≥ 4)	15

Most of the μ through the beam pipe

Reconstruction

decay	$K^\pm \to \pi^+\pi^-\pi^\pm$	$K^\pm \to \pi^o\pi^o\pi^\pm$
Acceptance (%)	45	6.5
K^+ / K^- decays reconstructed per cycle	23000 / 14000	500 / 300
m_K resol. (MeV/c^2)	1.5	1.2
p_K resol. (MeV/c)	450	350
Z vertex resol. (cm)	65	60
u resol.	$\lesssim 2 \cdot 10^{-2}$	$\lesssim 2 \cdot 10^{-2}$

Events collected per year:

$$7.3 \cdot 10^9\ K^+ \to \pi^+\pi^-\pi^+ + 4.4 \cdot 10^9\ K^- \to \pi^+\pi^-\pi^-$$

$$1.5 \cdot 10^8\ K^+ \to \pi^o\pi^o\pi^+ + 0.9 \cdot 10^8\ K^- \to \pi^o\pi^o\pi^-$$

With NO significant background
neither for $K^\pm \to \pi^+\pi^-\pi^\pm$ nor for $K^\pm \to \pi^o\pi^o\pi^\pm$

Systematics

- Systematics effects are minimized by the simultaneous beams
- Effects from accidentals are negligible
- Differential acceptance effects (from different K^+ / K^- spectra) are much reduced by analysis in p_K bins
- Taking data with regularly alternating spectrometer B field

  cancel ("B-odd") Left-Right asymmetric effects like:
  - Off-axis beam displacements
  - Asymmetries in efficiences of trigger, spectrometer, and muon-veto

Systematics

Residual effects ("B-even" not canceled by alternating B field)

- Differences in the intensity of the spectrometer B field up/down
- Spurious magnetic fields (fringe fields, Earth field)
- Trigger, spectrometer and muon-veto inefficiencies correlated with spectrometer B field
- Charge misidentification
- Differential probability for $\pi^{\pm}$ to interact with the spectrometer
- Differential punch-trough probability for $\pi^{\pm}$

⟹ Total systematic uncertainty

$$\delta A_g(syst.) < 0.5 \cdot 10^{-4}$$

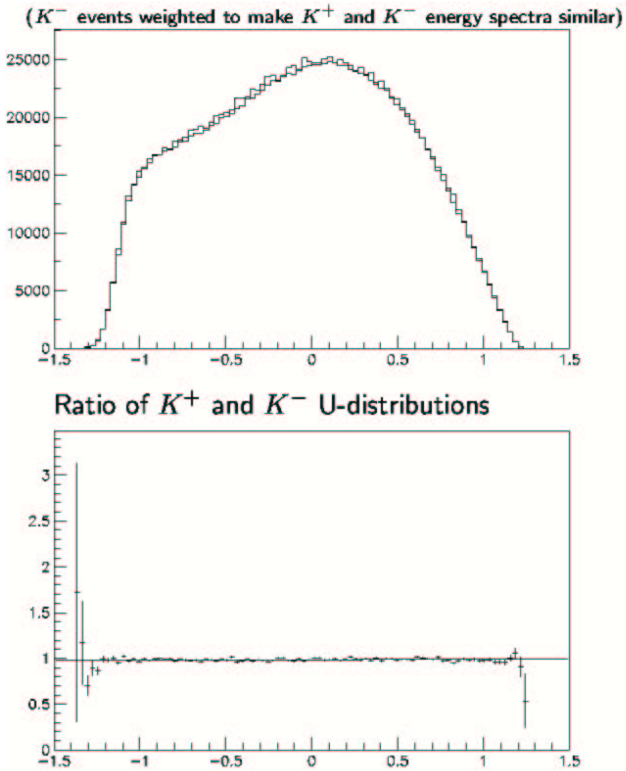
⟹ Limiting uncertainty given by statistics !!!

Statistics and Competition

Experiment	Decays	Statistics	δA_g (only stat.)
HyperCP (completed)	$K^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm}$	$4.5 \cdot 10^{8}$	$6 \cdot 10^{-4}$
KLOE (one year)	$K^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm}$	$1.5 \cdot 10^{8}$	$4.4 \cdot 10^{-4}$
	$K^{\pm} \rightarrow \pi^{o}\pi^{o}\pi^{\pm}$	$0.6 \cdot 10^{8}$	$6.3 \cdot 10^{-4}$
OKA (one year)	$K^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm}$	$5.9 \cdot 10^{9}$	$1.0 \cdot 10^{-4}$
	$K^{\pm} \rightarrow \pi^{o}\pi^{o}\pi^{\pm}$	$5.2 \cdot 10^{8}$	$1.3 \cdot 10^{-4}$
NA48 (one year)	$K^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm}$	$1.2 \cdot 10^{10}$	$0.7 \cdot 10^{-4}$
	$K^{\pm} \rightarrow \pi^{o}\pi^{o}\pi^{\pm}$	$2.4 \cdot 10^{8}$	$2.2 \cdot 10^{-4}$

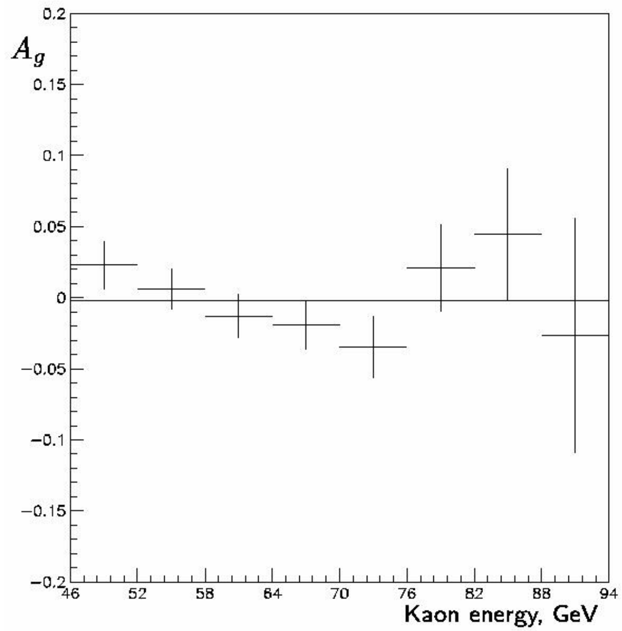
Test runs 2001

Data taking in 2001 (~ 1 day) with separated K^+ and K^- beams:
optimize the L1 and L2 TRIGGERS and check the BACKGROUND level



$\mathrm{K}^\pm$ events (and ratio) as a function of u

Asymmetry measured in 8 bins of p_K



$$A_g = (-1.7 \pm 7.1) \cdot 10^{-3}$$

No surprises !

Other channels

- CP symmetry can also be investigated in $K^{\pm} \rightarrow \pi^{\pm}\pi^{o}\gamma$ decays
- T symmetry can be investigated in $K^{\pm} \rightarrow \pi^{o}e^{\pm}\nu\gamma$ decays
- important χPT parameters can be measured with K_{e4}, $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$ decays
- from $K^{\pm}_{e3}$ decays f_V, f_S, f_T can be extracted
- The beam can be easily operated also in K_L mode
  ⟹ $K_L \rightarrow \pi^{+}\pi^{-}\pi^{o}$ as control channel for $K^{\pm} \rightarrow (3\pi)^{\pm}$

Conclusions

The NA48 post-ϵ'/ϵ program
is rich and promising:

2002 High Intensity $\mathrm{K_S}$ and neutral hyperon data taking
2003 Charged kaon $\mathrm{K}^{\pm}$ data taking

The new technique of
simultaneous unseparated $\mathrm{K}^{\pm}$ beams
will give NA48 a chance
to observe direct CP violation again

The Measurement is expected to be
limited only by statistics