NA48 future program : measurement of the direct CP violation in charged kaon decays

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- The origin of CP violation in particle physics is still an open problem ...

- From the pioneering experiment of Christenson, Cronin, Fitch and Turlay [Phys. Rev. Lett. 13 (1964), 128] we knew that, in neutral Kaon decays CP was violated; however, because of the mixing of the two CP eigenstates K_1 and K_2 in the K_L, K_S (described by ε...), only the most recent measurements of ε'/ε

[KTeV : Phys. Rev. Lett. 83 (1999), 22 → $(28.0 \pm 4.1) * 10^{-4}$
NA48 : Phys. Lett. 465B (1999), 335 → $(18.5 \pm 7.3) * 10^{-4}$]

have shown that, besides the mixing, there must be also a direct CP violation in the neutral Kaon decay dynamics ....
(described by ε' ...)

- Another very interesting decay that could shed some light on the problem of the <u>direct</u> CP violation, is the decay

$$K^{\pm} \rightarrow \pi^{\pm}\,\pi^{\mp}\,\pi^{\pm} \equiv (3\pi)^{\pm} \qquad [BR = 5.59\,\%]$$

Up to now, indirect / direct CP violation has been observed only in the neutral kaon system ($K \rightarrow 2\pi$), where $\varepsilon \sim 2.3 \cdot 10^{-3}$; $\varepsilon' \sim 5.7 \cdot 10^{-6}$.

Here, the indirect (mixing) contribution ε is possible since K_1 and K_2 are neutral, ... and this tends to mask ε' ... !

In $K^{\pm}$ decays, where $CP\,|K^{\pm}\rangle = |K^{\mp}\rangle$, no indirect contribution is possible, because charge superselection rule prevents mixing ... $\Rightarrow$ only <u>direct violation</u> (if any...)!

Let us consider in its rest frame, the decay

$$K^\pm \rightarrow (3\pi)^\pm$$

the differential decay rate $d\Gamma$ reads

$$d\Gamma = \underset{\substack{\uparrow \\ \text{K mass}}}{\frac{1}{2M}} \; \underset{\substack{\uparrow \\ \text{decay amplitude}}}{|\mathcal{M}|^2} \; d\phi \longleftarrow \text{phase space}$$

the 3-pion final state is completely defined (modulo a rotation) in terms of the two variables [cfr. S. Weinberg, Phys Rev Lett 4 (1960), 87]

$$(*) \quad u = \frac{s_0 - s_3}{m^2} \quad ; \quad v = \frac{s_1 - s_2}{m^2} \qquad \leftarrow \text{pion mass}$$

where

$$s_i = (P_K - p_{\pi_i})^2 = M^2 + m^2 - 2ME_i$$

$$s_0 = \frac{1}{3}(s_1 + s_2 + s_3) = m^2 + M^2/3$$

and $i = 3$ refers to the "odd" pion.

The allowed (u, v) region is defined by energy momentum conservation: we obtain

$$(u,v) : -u^3 \frac{m^2}{4M^2} + v^2 \frac{m^2}{4M^2} + 3 u^2 \frac{m^2}{4M^2} + u v^2 \frac{m^2}{4M^2} + $$

$$+ \frac{v^2}{12} + \frac{u^2}{4} - 3 + \frac{2}{3}\left(\frac{M}{m}\right)^2 - \frac{1}{27}\left(\frac{M}{m}\right)^4 \leq 0$$

→

... and, in terms of these variables $d\phi$ reads

$$d\phi = (2\pi)^4 \, \delta^4(P_f - P_i) \prod_{J=1}^{3} \frac{d^3K_J}{(2\pi)^3 \, 2E_J} =$$

$$= \frac{1}{4(2\pi)^3} dE_1 \, dE_2 = \left(\frac{1}{2\pi}\right)^3 \left(\frac{m^2}{4M}\right)^2 du \, dv$$

therefore any structure in the decay scatter plot yelds informations about $|\mathcal{M}|^2$!

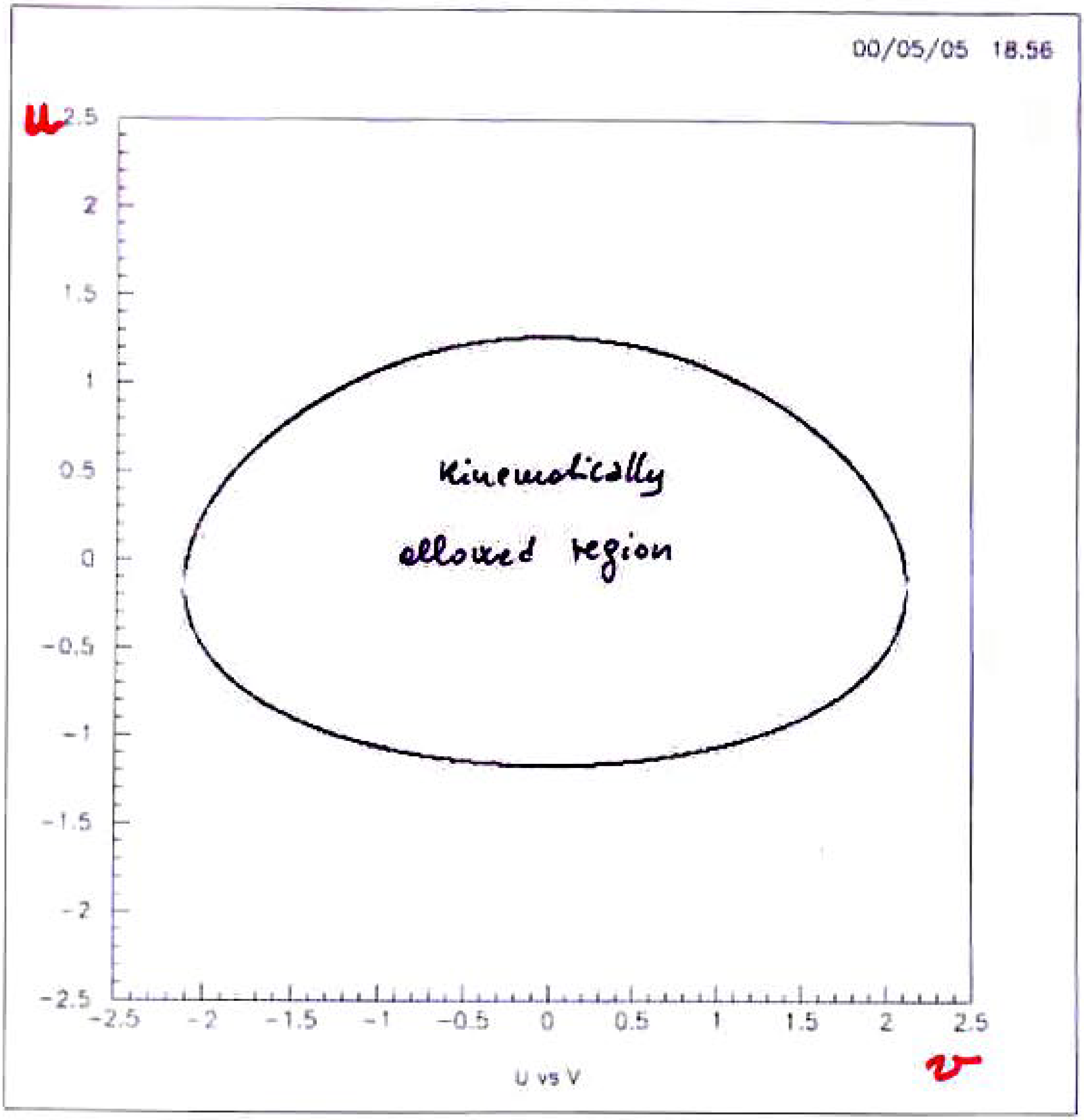
(if also the acceptance is flat in (u,v) ...).

[Dalitz - Fabri plot concept ...

Phil. Mag. 44 (1953), 1068

Phys. Rev. 94 (1954), 1046

Il Nuovo Cimento 11 (1954), 479]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-1
-0.5
0
0.5
1
1.5
2
2.5
Kinematically allowed region
U vs V
v

- The matrix element $|\mathcal{M}|^2$ is usually parametrized as follows [P.D.G. Eur. Phys. J. C3 (1998), 449]

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

- If the slope g for K^+ and K^- is not the same, i.e. if the asymmetry

$$A_g \equiv \frac{g^+ - g^-}{g^+ + g^-} \equiv \frac{\Delta g}{2g_0} \neq 0 \qquad \left[g^\pm \equiv g^0 \pm \Delta g/2 \, ; \; g^0 = -0.2154 \pm 0.0035 \right]$$

Then, this would indicate the presence of a direct CP violation in the decay process.

- According to recent theoretical results, we can expect A_g asymmetries as high as 10^{-4} ....

5bis

INFNNA-99/39
LPT ORSAY 99/99

Direct CP violation in $K \to 3\pi$ decays induced by SUSY chromomagnetic penguins[*]

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Abstract

An analysis of the CP violating asymmetry in $K^\pm \to (3\pi)^\pm$ decays in the Standard Model and, by means of the mass insertion approximation, in a wide class of possible supersymmetric extensions, is presented. We find that the natural order of magnitude for this asymmetry is $\mathcal{O}(10^{-5})$ in both cases. Within supersymmetric models effects as large as $\mathcal{O}(10^{-4})$ are possible, but only in a restricted range of the relevant parameters.

November 1999

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- The quantity to be measured in order to extract Δg, is the ratio

$$r(u) = \frac{\int dv\, |\mathcal{M}^+(u,v)|^2}{\int dv\, |\mathcal{M}^-(u,v)|^2} \simeq \frac{1+g^+u}{1+g^-u}$$

and, since the differential decay rate $d\Gamma$ reads

$$d\Gamma^\pm = \frac{1}{2M}\, |\mathcal{M}^\pm|^2\, d\phi^\pm = K\,(1+g^\pm u + \dots)\; du\; dv$$

with K independent from the kaon charge (CPT...),

to evaluate Δg we can measure

$$\frac{\int \mathcal{N}^+(u,v)\, dv}{\int \mathcal{N}^-(u,v)\, dv} = \frac{\mathcal{N}^+(u)}{\mathcal{N}^-(u)} = \underbrace{\frac{\mathcal{N}_0^+}{\mathcal{N}_0^-}}_{\text{total number of decays}} \cdot\, r(u)$$

where $\mathcal{N}^\pm(u)$ are the differential spectra of the $K^\pm \to (3\pi)^\pm$ decays happened.

However, the $K^\pm \to (3\pi^\pm)$ spectra observed experimentally $N^\pm(u,v)$ are only proportional to $\mathcal{N}^\pm(u,v)$ through the detector acceptance :

$$N^\pm(u,v) = \mathcal{N}^\pm(u,v) * A^\pm(u,v)$$

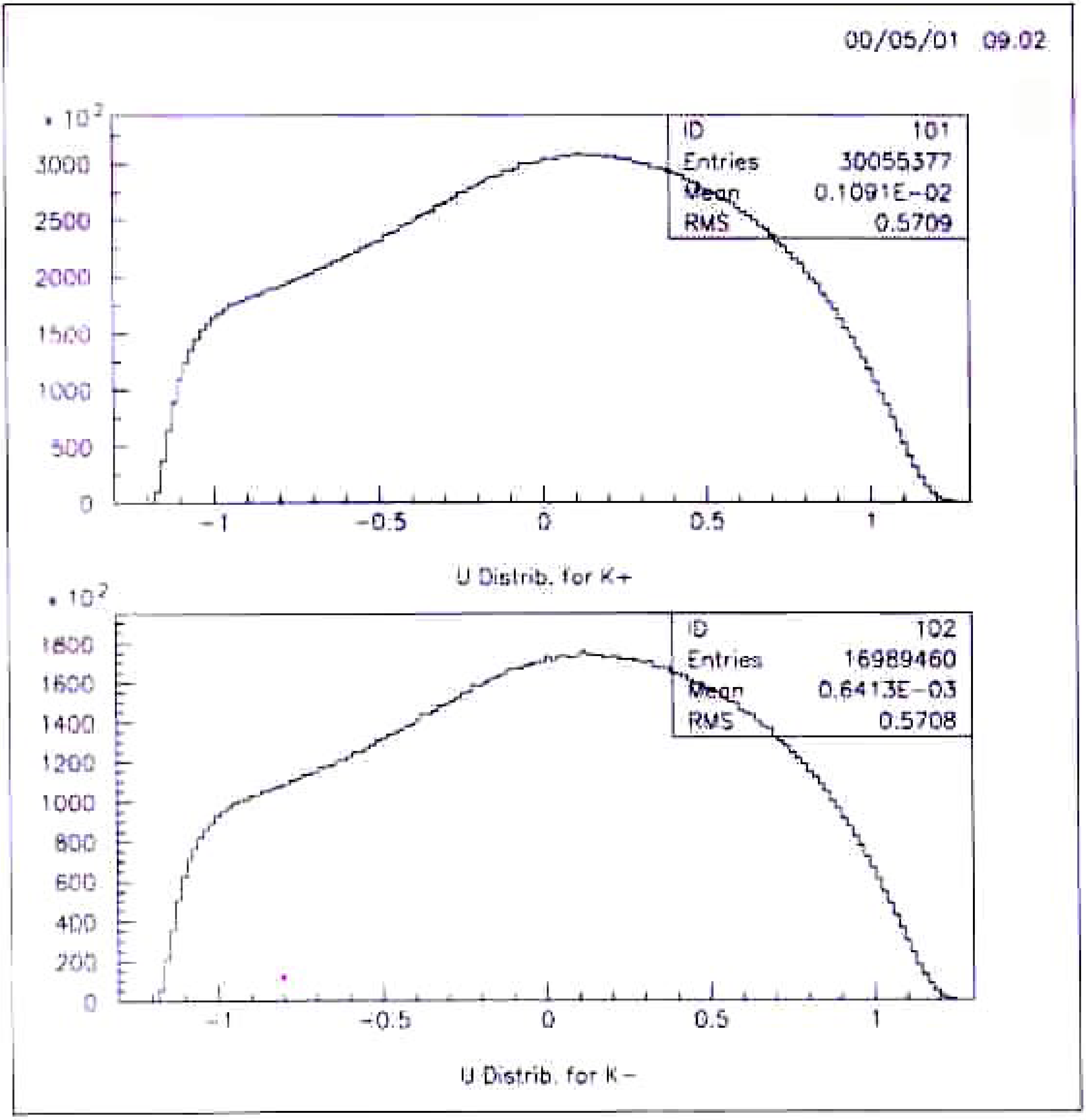
→

and only if the acceptance is independent from the K charge, we still have

$$R(u) \equiv \frac{\int N^+(u,v)\,dv}{\int N^-(u,v)\,dv} \equiv \frac{N^+(u)}{N^-(u)} = \frac{N_0^+}{N_0^-} \cdot r(u)$$

i.e., we can evaluate $r(u)$ without needing to introduce acceptance (MC) corrections !

(7bis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U Distrib. for K+
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1400
1200
1000
800
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200
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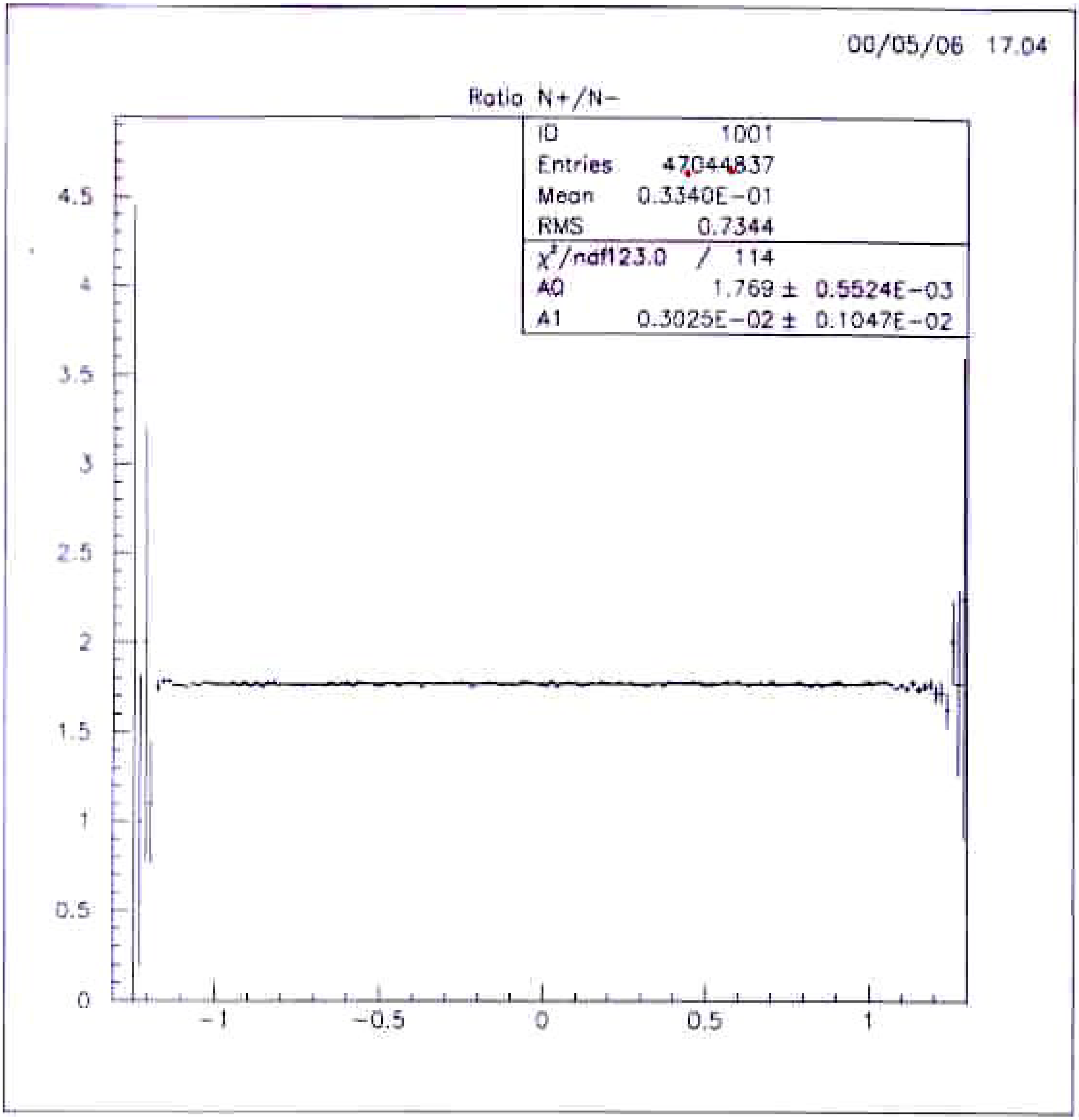
U Distrib. for K−

(7 ter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χ²/ndf 123.0 / 114
A0 1.769 ± 0.5524E-03
A1 0.3025E-02 ± 0.1047E-02
4.5
4
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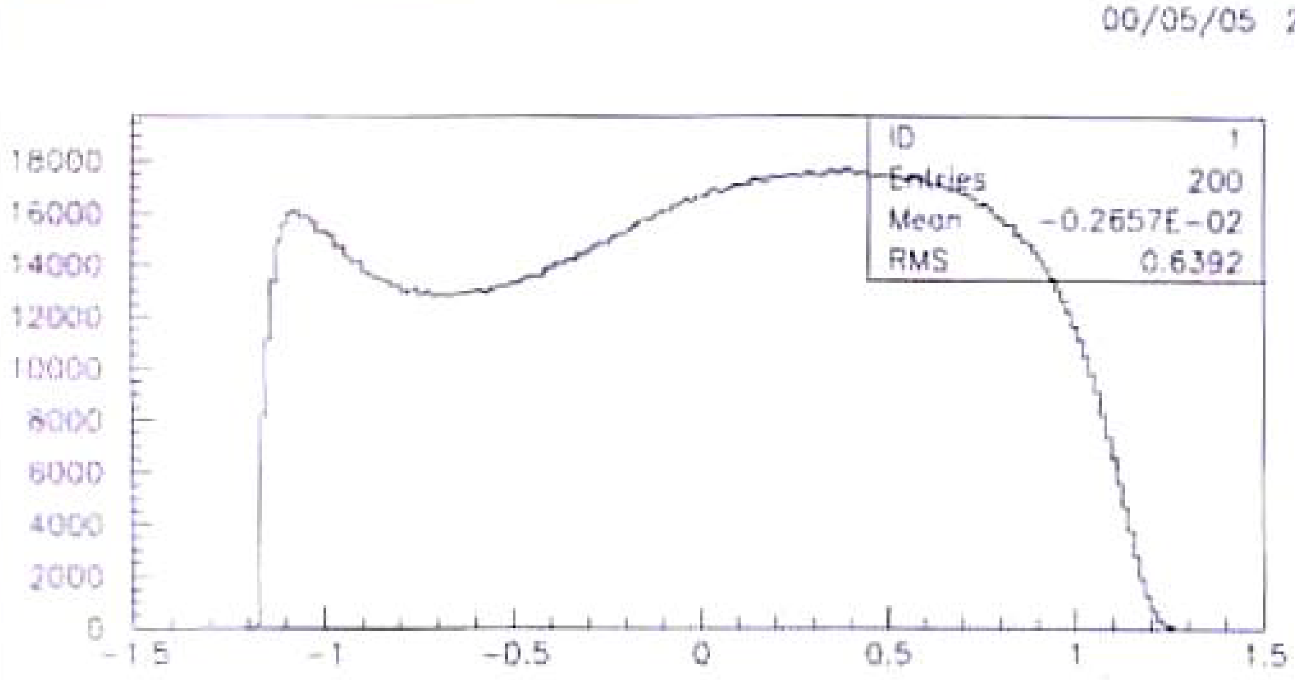
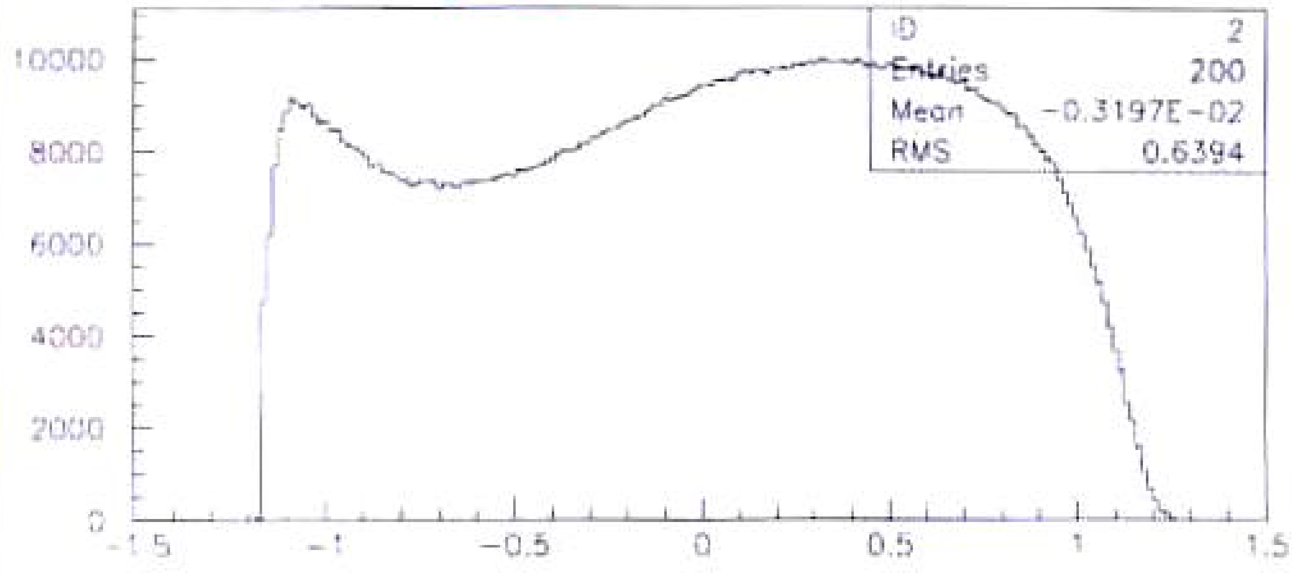
7quater



U weighted distrib. for reconstructed K+



U weighted distrib. for reconstructed K−

$$\text{weight} = \frac{1}{\text{phase space}}$$

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/SPSC 2000-003
CERN/SPSC/P253 add.3
December 14, 1999

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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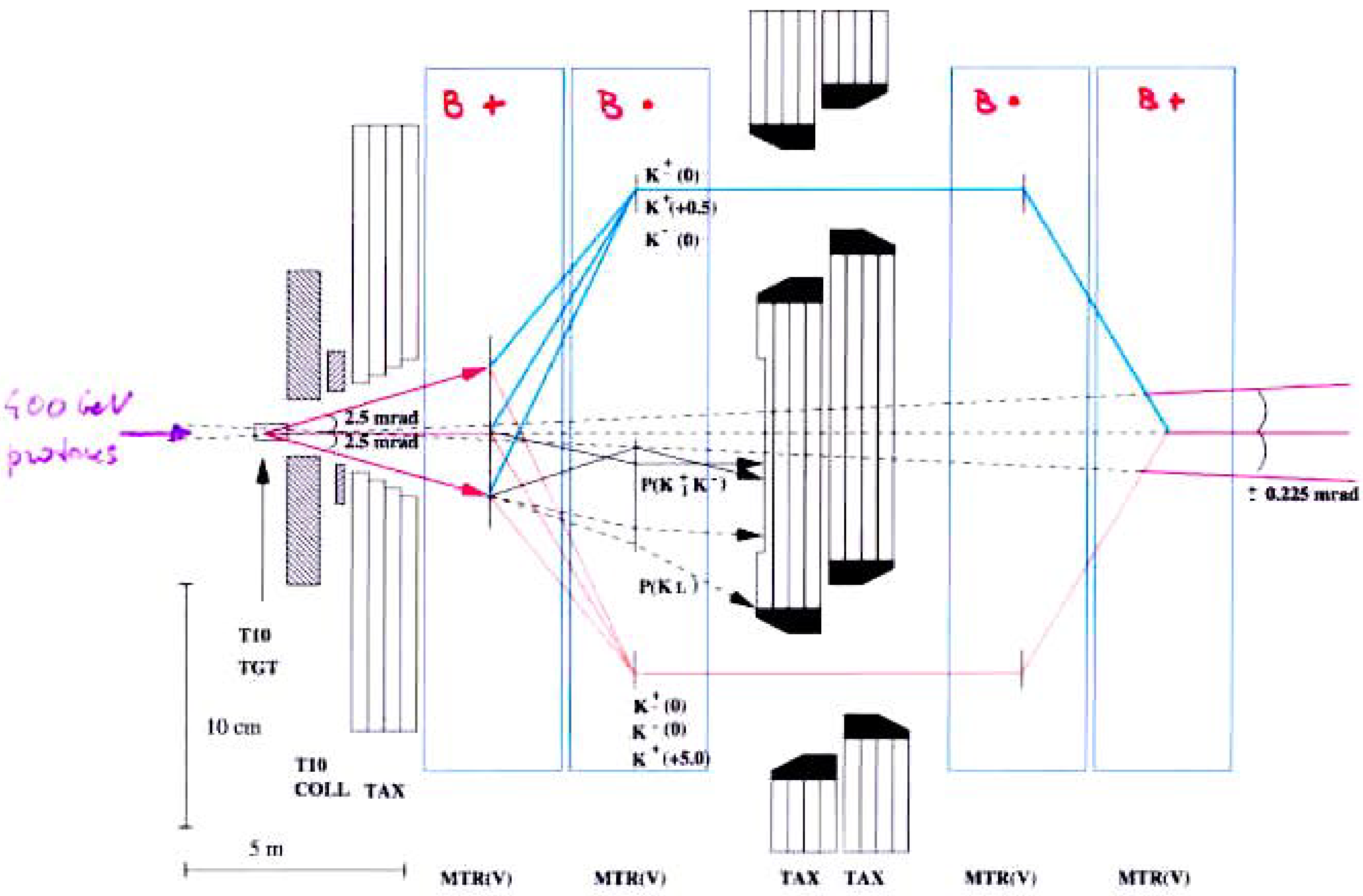
Simultaneous K^+ and K^- beams (front end achromat)



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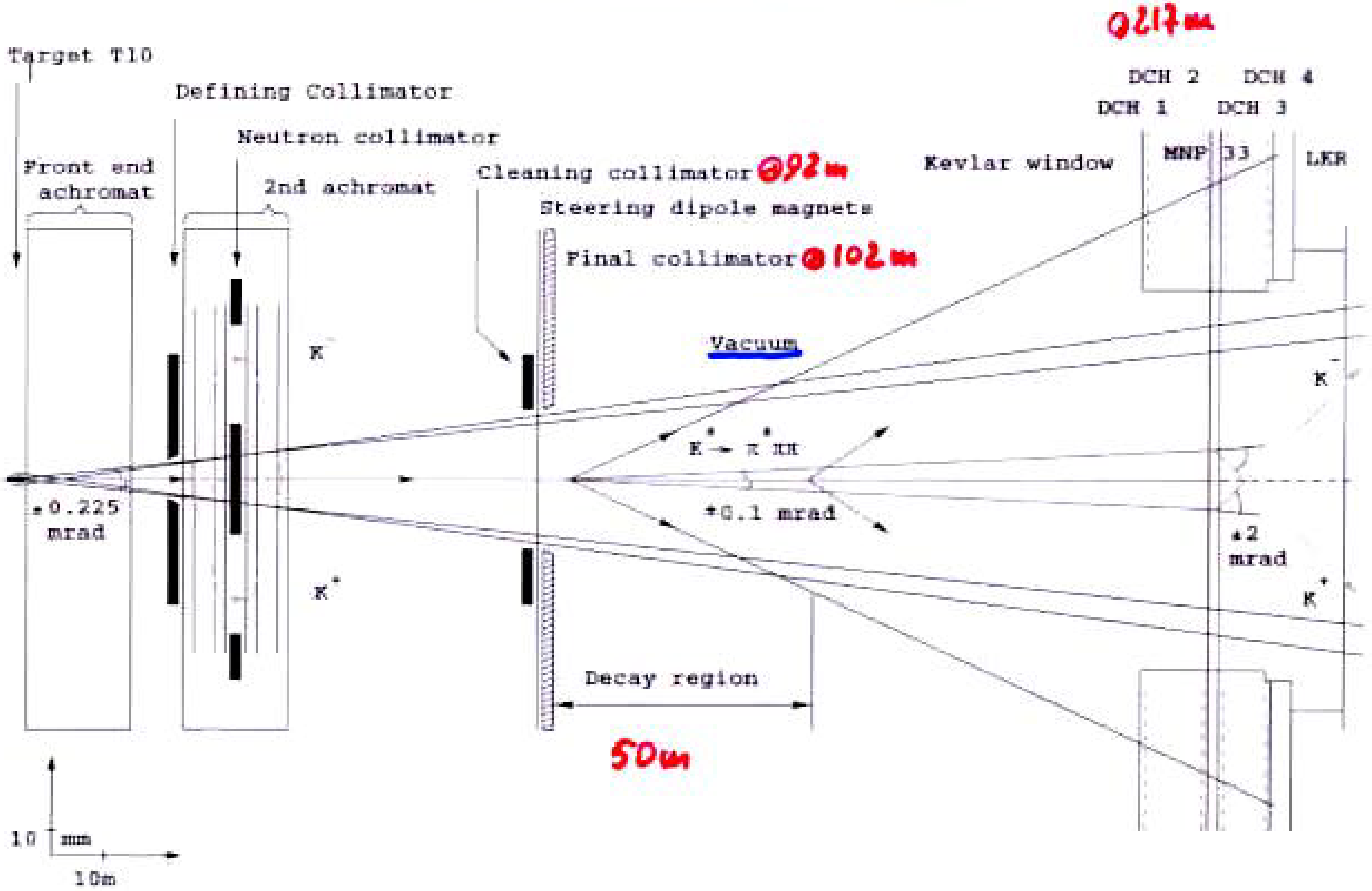
Schematic layout of K^+ and K^- beams



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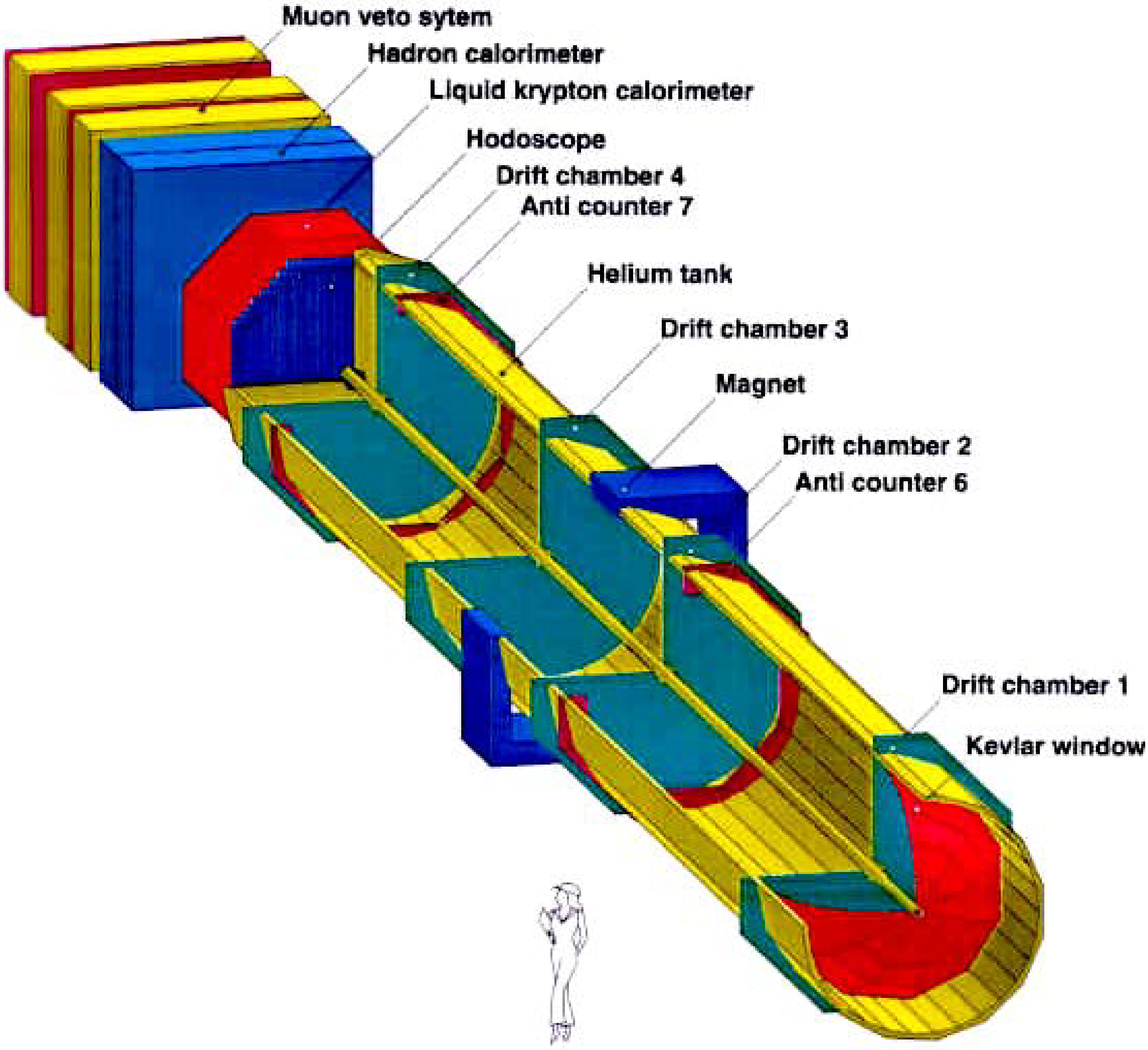
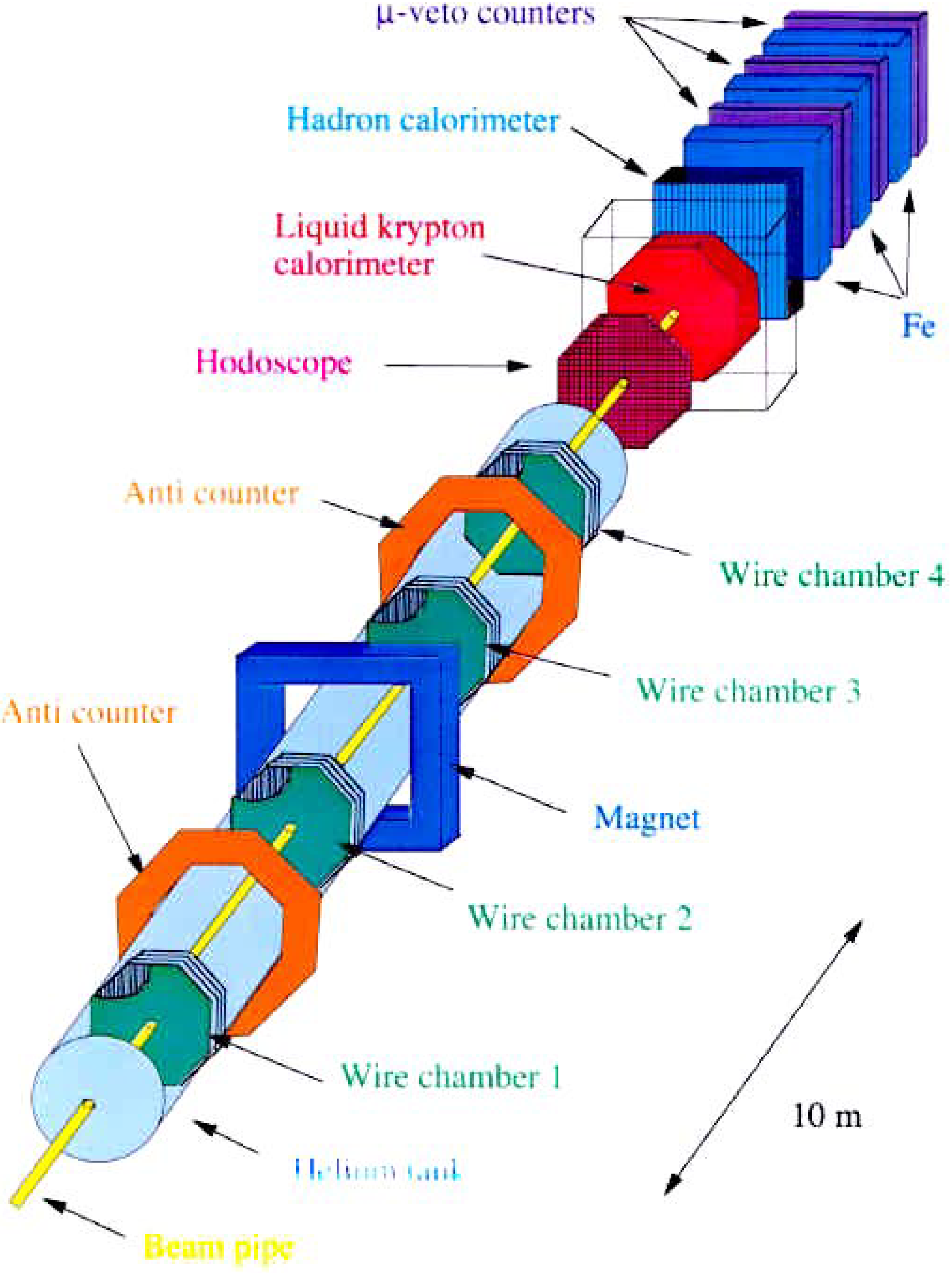

Muon veto sytem
Hadron calorimeter
Liquid krypton calorimeter
Hodoscope
Drift chamber 4
Anti counter 7
Helium tank
Drift chamber 3
Magnet
Drift chamber 2
Anti counter 6
Drift chamber 1
Kevlar window

8 quinquies

The NA48 Detector



Guidelines of the experiment
that we are proposing ...

A) Use simultaneous $K^\pm$ beams, overlapping in space ;

→

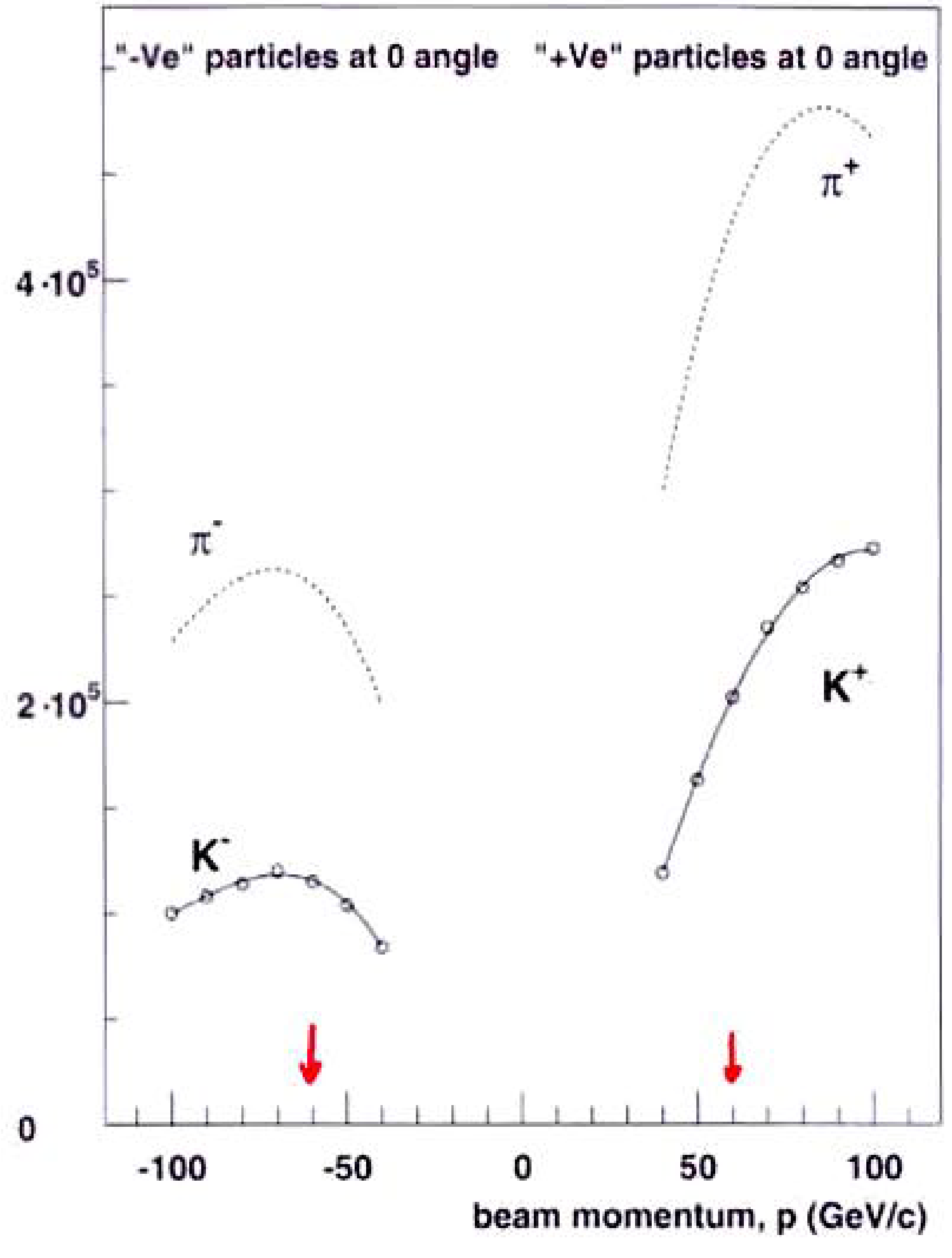
B) Use a detector as symmetric as possible around the decay axis ;

→

C) Operate at alternate magnetic field in the spectrometer, to average any residual acceptance difference for K^+ and K^- ;

D) Evaluate the ratio $R(u)$ independently in each $K^\pm$ energy bin .

8 nixies


"-Ve" particles at 0 angle
"+Ve" particles at 0 angle
π^+
π^-
K^+
K^-
$4 \cdot 10^5$
$2 \cdot 10^5$
0
-100
-50
0
50
100
beam momentum, p (GeV/c)

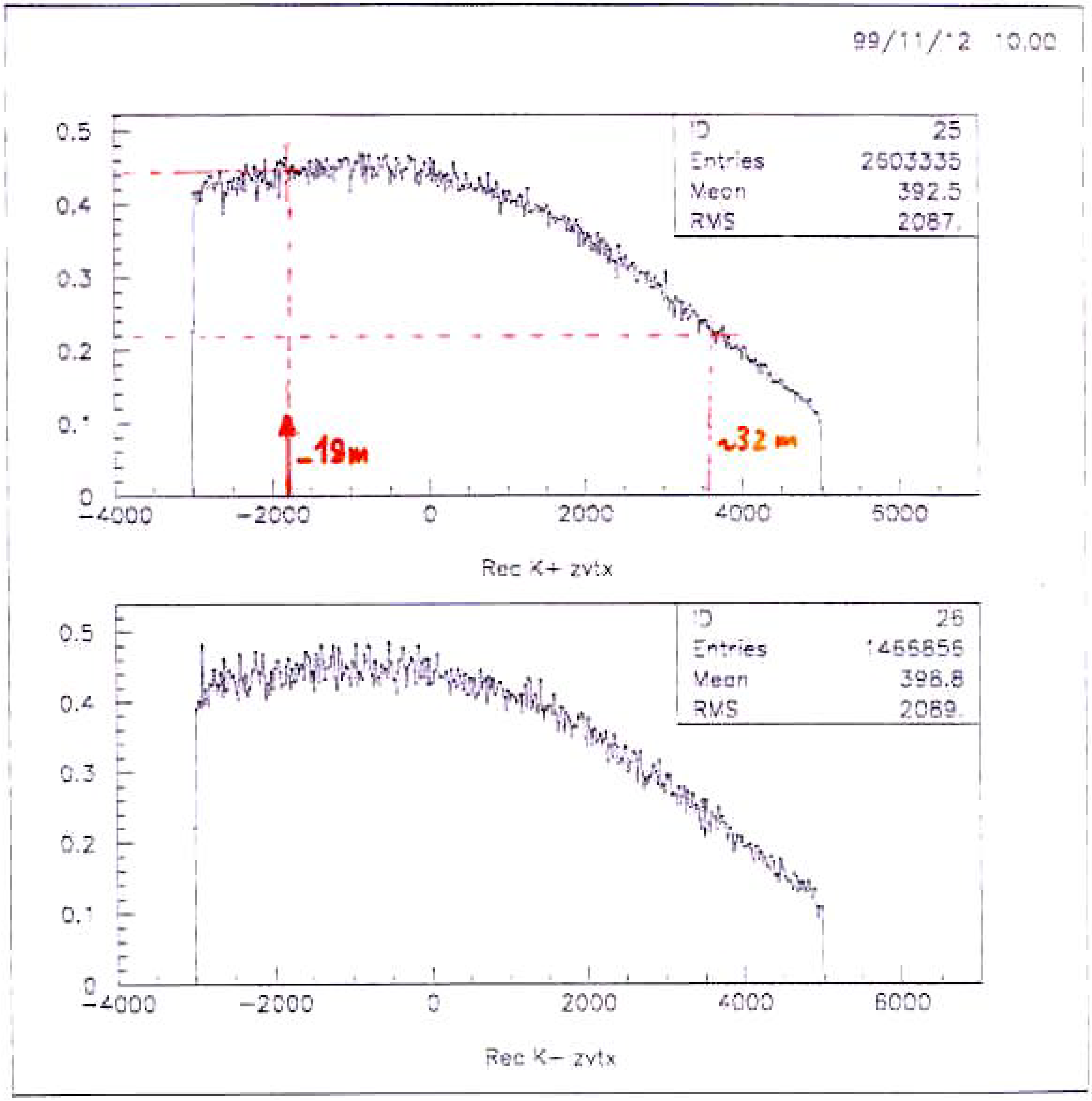
- The $K^{\pm}$ beams have been optimized to obtain maximum acceptances, given the NA48 detector geometry ....

⇓

Beam characteristics

Proton energy	400 GeV
Protons per pulse on target	$1. * 10^{12}$
Production angle	0°
Beam acceptance	± 0.225 mrad
Target-to-final coll. distance	102 m
Decay region	$107 \leq Z \leq 157$ m
Central $K^{\pm}$ energy	60 GeV
Momentum spread	$\Delta p/p = \pm 10\%$
Average acceptance	38 %
Number of K^{+}/K^{-} reconstructed (per pulse)	5000/3000

Acceptance @ $E = (60 \pm 6)$ GeV

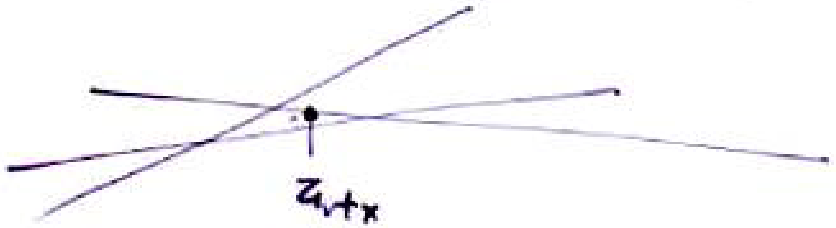


■ Event reconstruction

i) at least 3 space points at each chamber;

ii) at least 3 straight lines in the non bending plane;

iii) a suitable value of the minimum distance in the transverse plane among the 3 above tracks, as a function of z

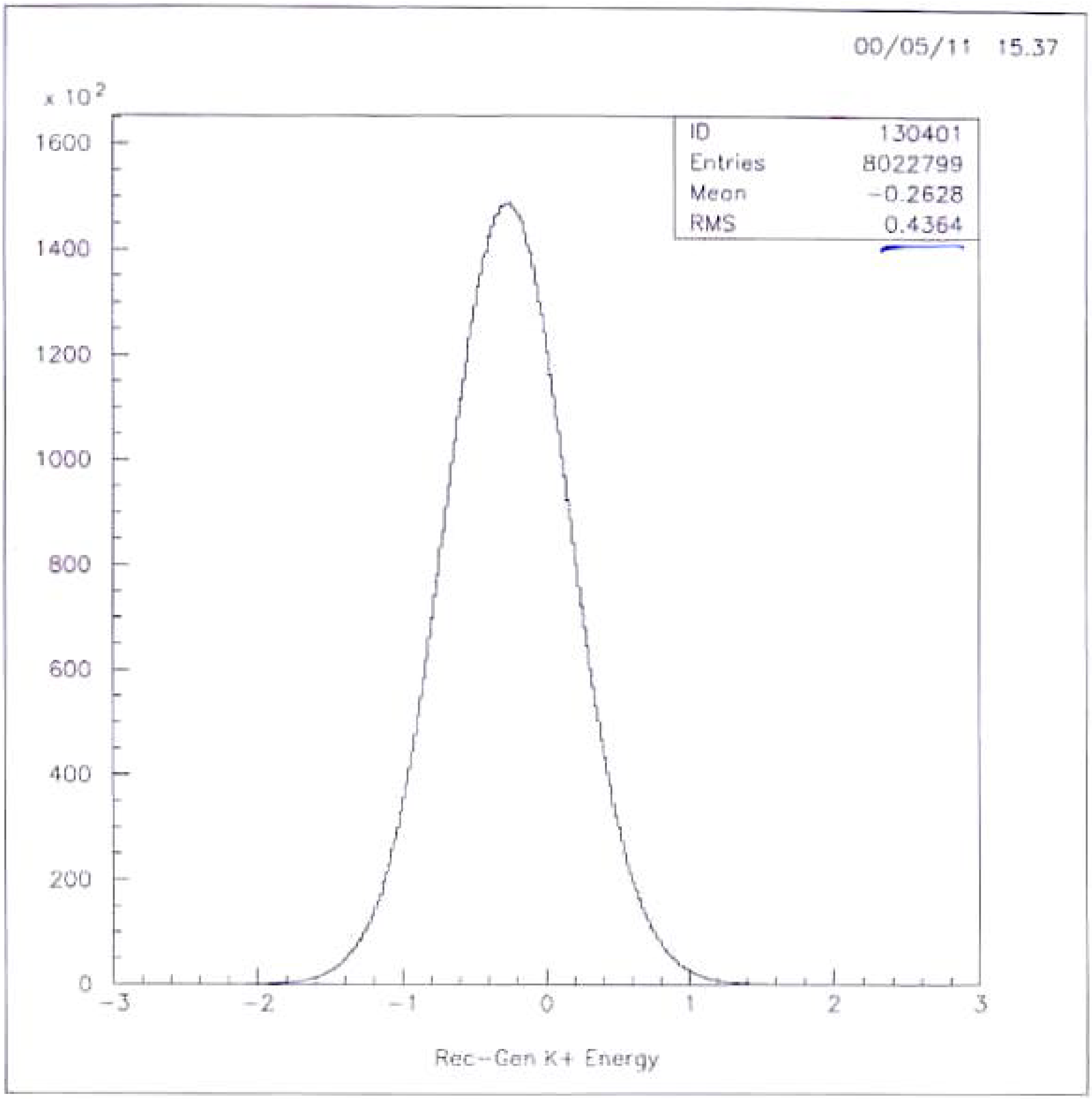


CDA ≤ 2.5cm

iv) no muon hits

⇓

•)	K mass resolution	1.5 MeV	
••)	K energy resolution	0.44 GeV	(*)
•••)	z vertex resolution	65 cm	
•v)	u resolution	$3.3*10^{-2}$	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3
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Mean -0.2628
RMS 0.4364
Rec--Gen K+ Energy

Systematic uncertainties

B-odd effects:

In principle, the B-odd systematics cancels if both runs (B↑ and B↓) have been taken with the detector in the same conditions, i.e.

a) with the same B intensity in the spectrometer;

b) with the same detector efficiencies,

.....

⇒ reverse the field ~ 8 hours ...

Systematic effects of this type are due, f.i., to

.) L-R non symmetric chamber efficiency;

..) L-R non symmetric trigger efficiency;

...) off-axis $K^{\pm}$ beams displacements;

....

B even effects:

We have considered, f.i.

•) different $K^\pm$ acceptances, due to ≠ energy spectra

$\Rightarrow$ need to evaluate $R(u)$ independently, in the various energy bins ... ($\Delta E = \pm 0.5\,\text{GeV}$)

••) Earth magnetic field + residual spurious B fields;

•••) different $\pi^\pm N$ cross sections;

•v) possible chamber inefficiencies B correlated;

v) differential backgrounds effects;
(two close track ch. ineff. ...)

vi) punch-through $\pi^\pm$ differential effects;

vii) accidental inefficiencies;

viii) residual systematic of B-odd type due to
$B\uparrow \neq B\downarrow$ (0.5% ...)

...

$$\Rightarrow \Delta A_g < 5 * 10^{-5}$$

Statistical limit

The ratio to be evaluated is

$$R(u_i) = \frac{N^{+}(u_i)}{N^{-}(u_i)} = a + \underbrace{b}_{= a \cdot \Delta g} u_i$$

From the best fit (χ^2 min.) analysis

$$a = \frac{\gamma D - \beta F}{\alpha\gamma - \beta^2} \quad ; \quad b = \frac{\alpha F - \beta D}{\alpha\gamma - \beta^2}$$

$$(\delta a)^2 = \frac{\gamma}{\alpha\gamma - \beta^2} \quad ; \quad (\delta b)^2 = \frac{\alpha}{\alpha\gamma - \beta^2}$$

where

$$\alpha = \sum_i \frac{1}{\sigma_i^2} \quad ; \quad D = \sum_i \frac{R(u_i)}{\sigma_i^2}$$

$$\beta = \sum_i \frac{u_i}{\sigma_i^2} \quad ; \quad E = \sum_i \frac{R^2(u_i)}{\sigma_i^2}$$

$$\gamma = \sum \frac{u_i^2}{\sigma_i^2} \quad ; \quad F = \sum \frac{u_i\, R(u_i)}{\sigma_i^2}$$

In our case

$$\sigma_i \simeq \frac{N_i^+}{N_i^-}\sqrt{\frac{1}{N_i^+}+\frac{1}{N_i^-}}$$

and, since $b \ll 1$ $\Rightarrow$ $N_i^+ \simeq a\, N_i^-$ $[a \sim 1.78 \ldots]$

$\Rightarrow$ $\sigma_i \simeq (1+a)\sqrt{\frac{a}{N_i}}$ where $N_i \equiv N_i^+ + N_i^-$

We obtain $\left(\mathcal{N}_T \equiv \sum_i N_i\right)$

$$\alpha = \frac{\mathcal{N}_T}{a(1+a)^2} \; ; \quad \beta = \frac{\sum u_i N_i}{a(1+a)^2} \; ; \quad \gamma = \frac{\sum u_i^2 N_i}{a(1+a)^2}$$

$$\Rightarrow (\delta \Delta g)^2 \simeq \left(\frac{\delta b}{a}\right)^2 = \frac{(1+a)^2}{a} \cdot \frac{1}{\mathcal{N}_T \cdot \sigma^2}$$

where σ^2 is the rms of the u-distribution of the $K^+ + K^-$ accepted decays ... $[\sigma \sim 0.57 \ldots]$ →

$$\Rightarrow \boxed{\delta A_g = 10^{-4} \iff \mathcal{N} \sim 7 * 10^9 \text{ decays}}$$

i.e. ~ 900 000 bursts (8000 accept. ev./burst ...)

$\Rightarrow$ 1.5 years of data taking

Conclusions

The measurement appears to be, essentially, statistically limited and it should reach the interesting sensitivity of

$$\delta A_g \sim 10^{-4}$$

in 1.5 years of data taking.

this would be ~ 50 times better than the present result $A_g = (-7 \pm 5) \cdot 10^{-3}$

[Ford et al.: Phys. Rev. Lett. 25, 1370 (1970)]