Prospects for the study of the $K^{\pm}e4$ decays at the NA48/2 experiment

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October 14-15, 2002
HadAtom02

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NA48/2: Main goals

- Direct CP violation in the asymmetry of the Dalitz plots for $K^+ \to 3\pi$ and $K^- \to 3\pi$ decays

  Dalitz plot distribution:

  $$|M_{K^\pm \to 3\pi}(u,v)|^2 \propto 1 + gu + hu^2 + kv^2$$

  $$\text{Direct CP-v} \Rightarrow A_g = \frac{g^+ - g^-}{g^+ + g^-} \neq 0$$

- $\pi\pi$ scattering length a_0^0 from analysis of $K^\pm \to \pi^+\pi^- e^\pm \nu_e$ decays

- Study of some $K^\pm$ rare decays:
  $K^\pm \to \pi^\pm \pi^0 \gamma$,$K^\pm \to \pi^\pm ll$,$K^\pm \to \pi^\pm \gamma\gamma$,$K^\pm \to \pi^\pm \gamma\gamma\gamma$ and etc.

- NA48/2 (in 2003): $\approx 1 \times 10^{11}$ K^+ and 0.6×10^{11} K^- decays in 50m of the decay volume

NA48/2 Setup

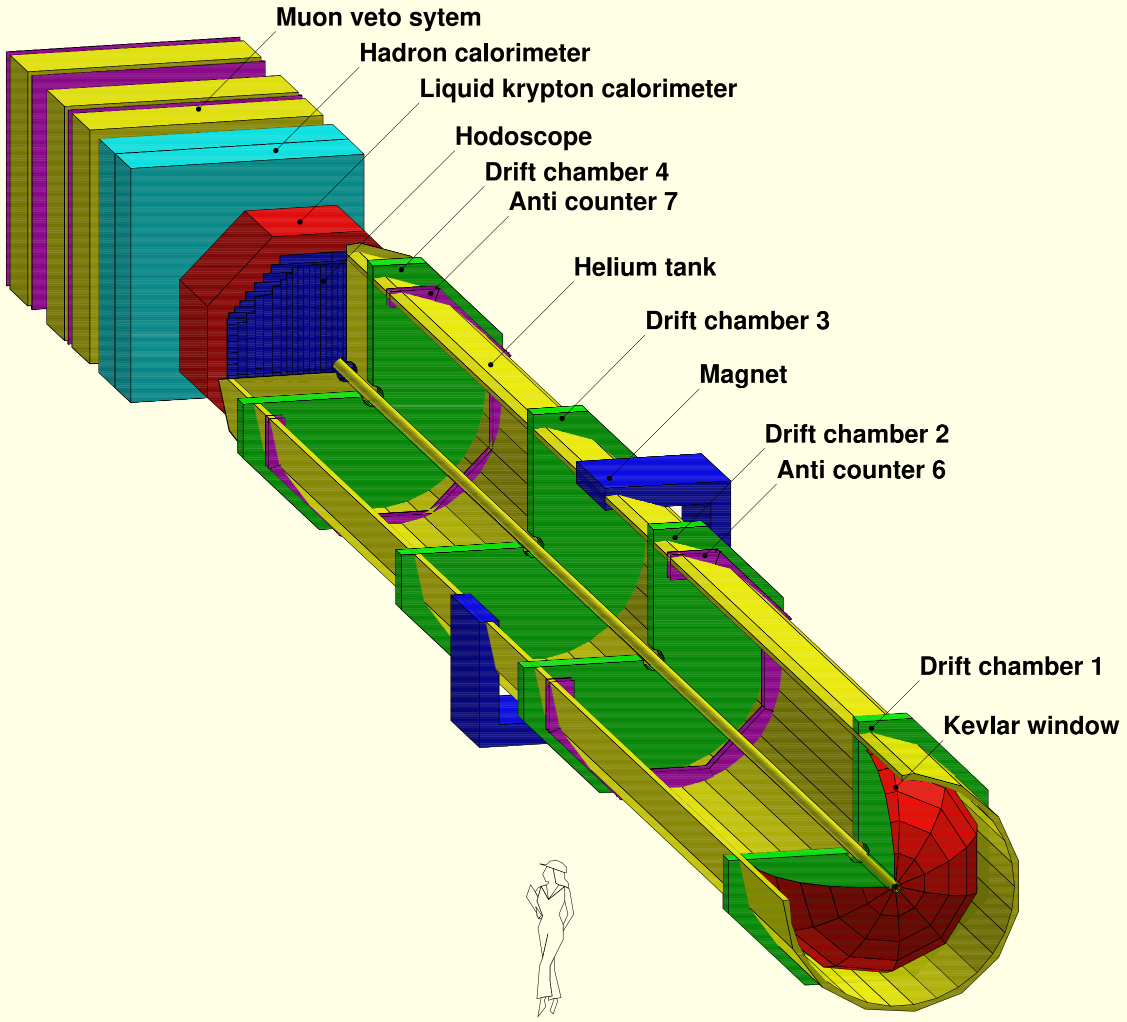
- Present NA48 setup

+

- Simultaneous K^+ and K^- beams
  $\Rightarrow$ to minimize the systematics for the $K \to 3\pi$ asymmetry measurement

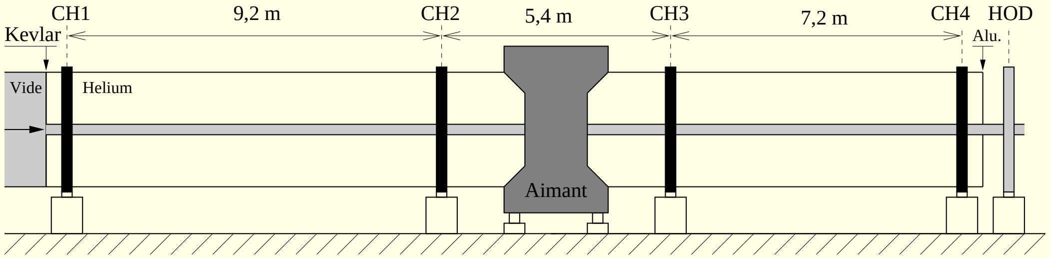
- KAon BEam Spectrometer (KABES)
  $\Rightarrow$ to measure the kaon sign, momenta and direction for:
  - reconstruction of $K^{\pm}e4$
  - reconstruction of $K \to 3\pi$ with one pion undetected

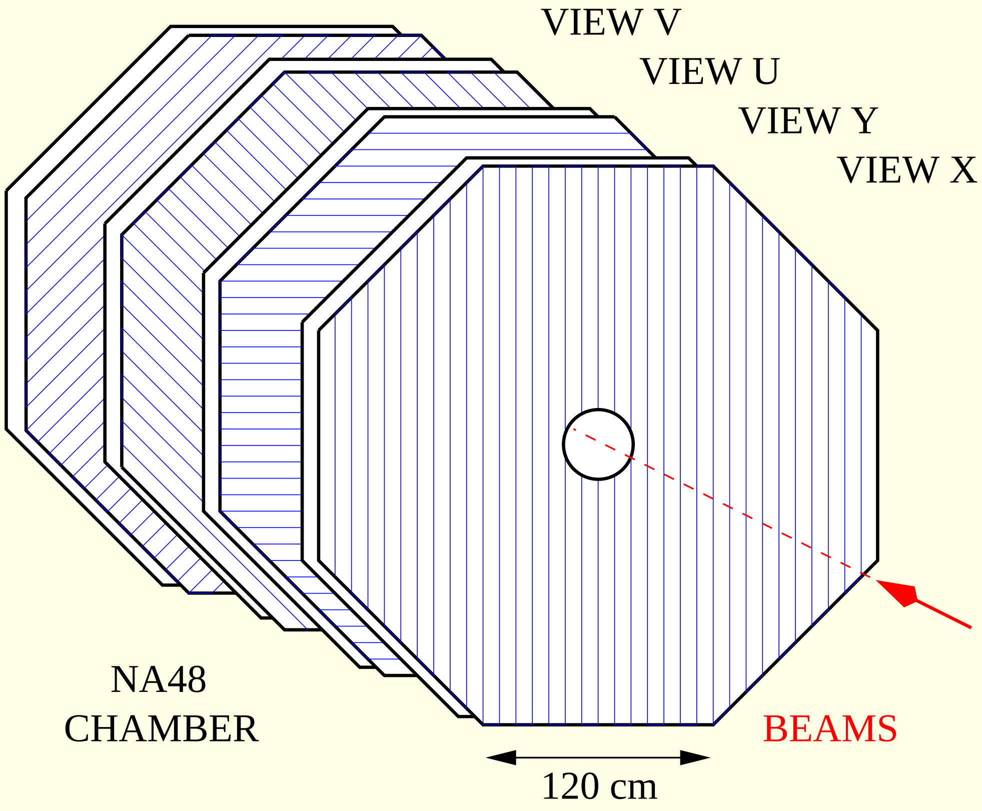
NA48 Detector



- Charged particles magnetic spectrometer ($P_{kick} \sim 120MeV/c$)
  Momentum resolution:
  $\sigma_P/P[\%] \approx 0.48 \oplus 0.02 \times P[GeV/c]$
  Time resolution: ~ 1 ns / track
- Liquid Krypton e/m calorimeter

Magnetic spectrometer





Each chamber consists of 8 planes $\times$ 256 wires

5 mm drift distance

$t_{drift} \sim 100\ ns$

Space resolution

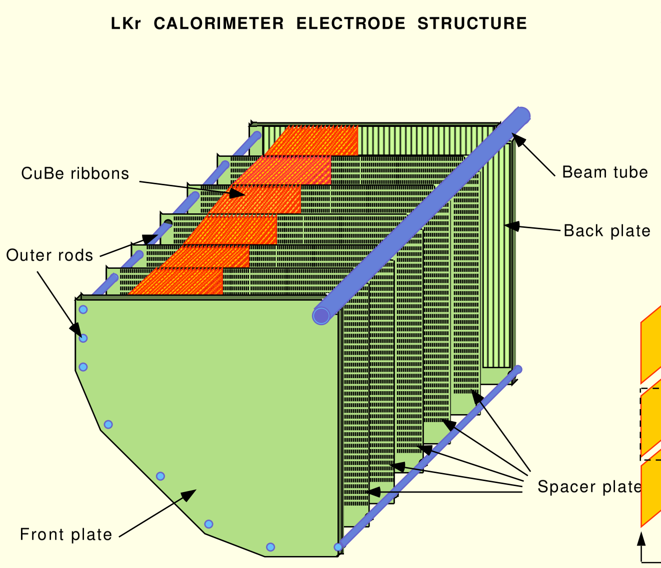
$\sigma_{X,Y} = 90\ \mu m$

Time resolution

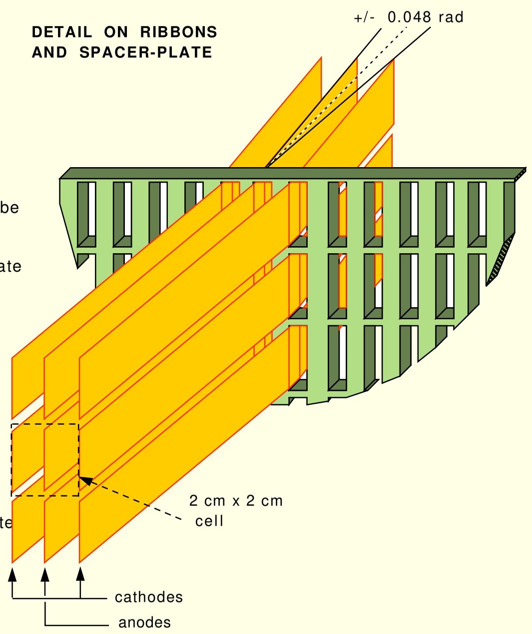
$\sigma_t \sim 1\ ns$ / track

Liquid Krypton e/m calorimeter (LKr)

- Quasi-homogeneous detector 10 m^3 liquid krypton (120 K) ($X_0 = 4.7cm$, $R_M = 6.1cm$, $\lambda = 60cm$)
- 13212 cells each with size of $2 \times 2\ cm^2$
- Longitudinal size $1.25m$ ($\sim 27X_0$, $\sim 2\lambda$)
- Projective geometry pointing to decay volume
- Accordion geometry (± 48 mrad) to diminish anode effects



A quarter of calorimeter

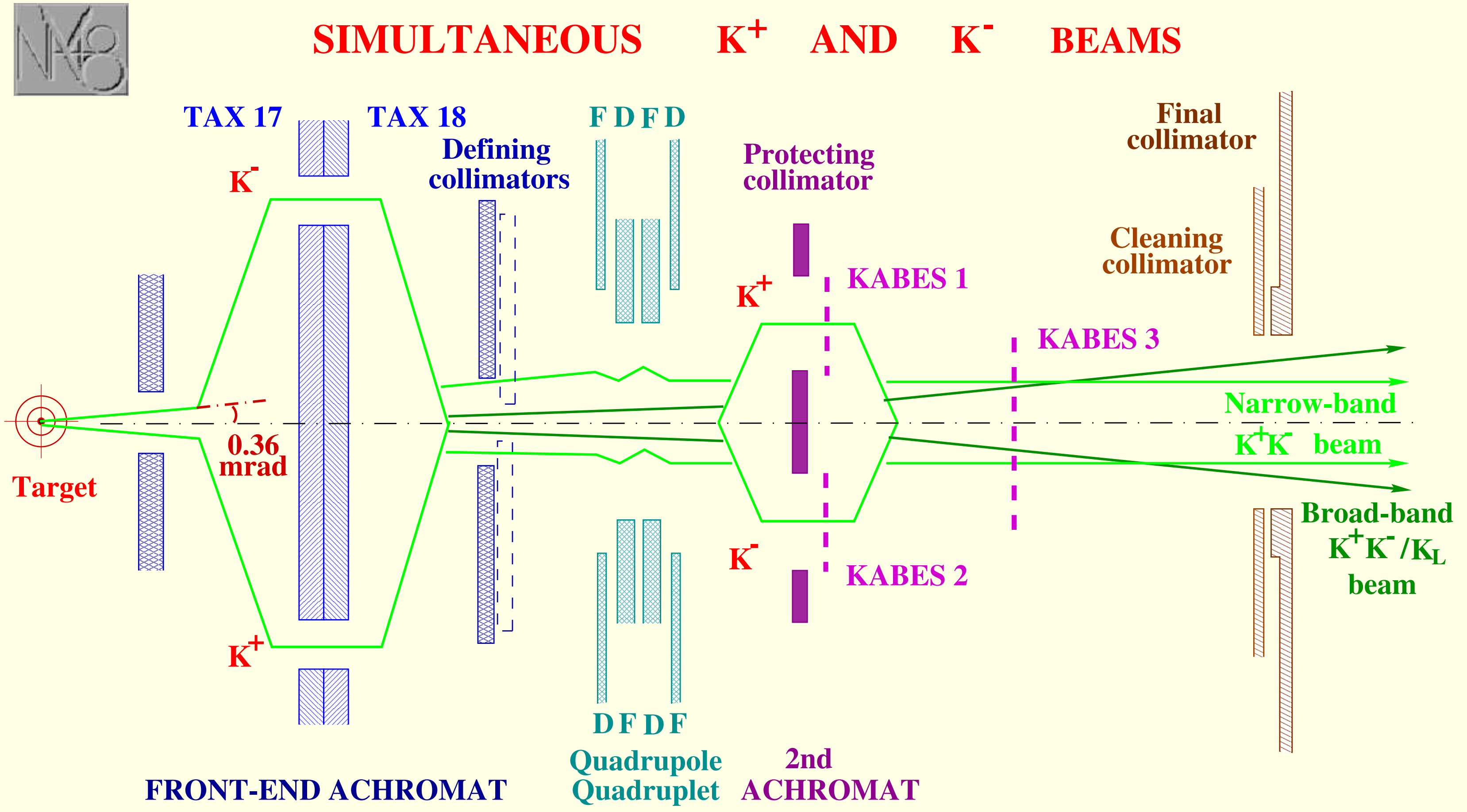


Ribbons and spacer

Resolution for e/m showers:

- Energy: $\sigma_E/E = 0.42\% \oplus 3.2\%/\sqrt{E} \oplus 0.09/E$
- Time: < 300 ps (E $>$ 20 GeV)
- Spatial: < 1.3 mm

Simultaneous K^+ and K^- beams



- Momentum 60 GeV $\pm$ 10% (RMS 3.7%)
- Beam divergence $\approx$ 0.02 mrad

KABES

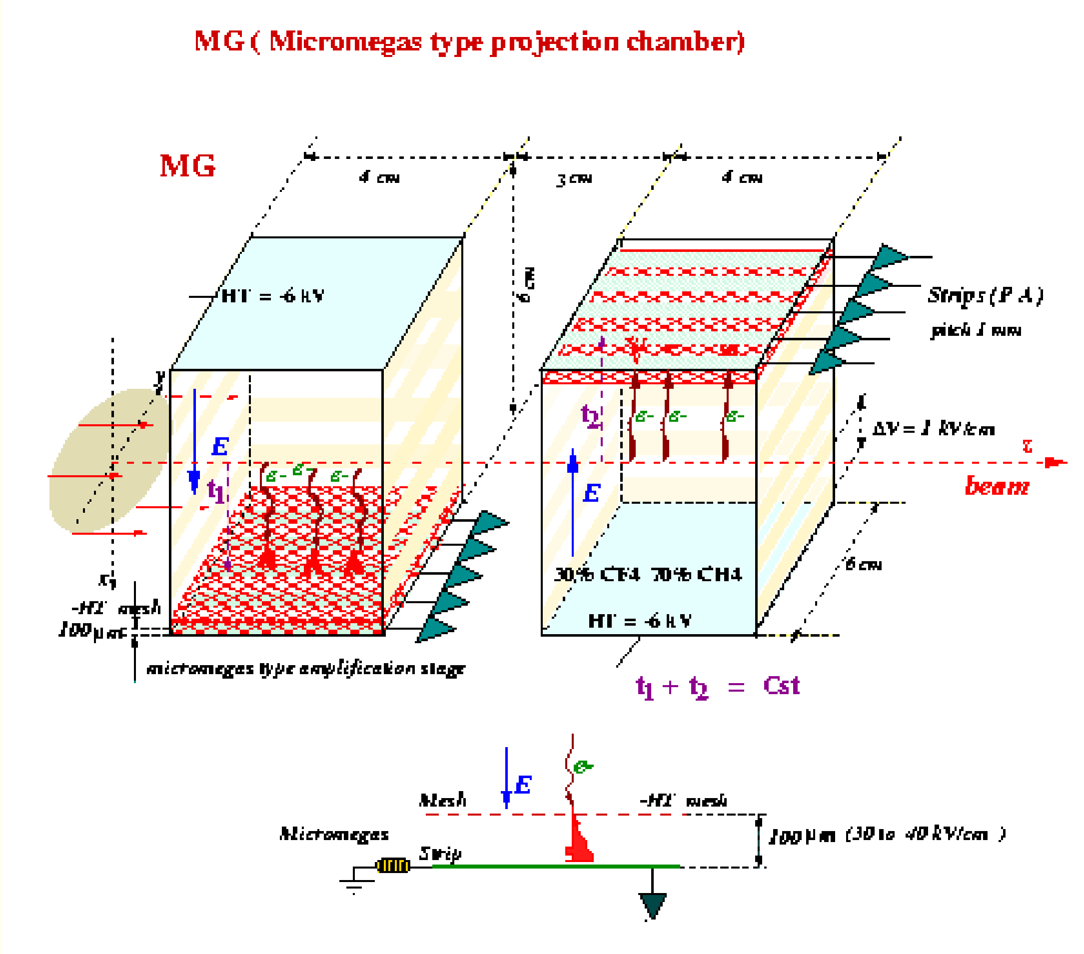
- KABES consists of 3 stations: 2 in the second achromat and one just after it
- By measuring the beam track coordinates in the stations
  $\Rightarrow$ track sign, momentum, position and direction

KABES performance (based on a prototype test run in July 2002):

- < 0.5 ns time resolution
- $< 1\%$ resolution on momentum
- detector stands extremely high particle rate ($20 - 30$ MHz)

KABES

Each KABES station consists of two MICROMEGAS chambers which work in TPC regime



- Sum of the drift times in the chambers $\Rightarrow$ time of the track
- Difference between the drift times $\Rightarrow$ X position of the track
- Strip indexes $\Rightarrow$ Y position of the track

$K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e$

- $\pi\pi$ interaction at the threshold

  $\Rightarrow$ scattering length a_0^0

  $\Downarrow$

  size of the quark condensate $< 0|u\overline{u}|0 > < 0|d\overline{d}|0 >$

- Form factors are important input to ChPT

Two significant experiments so far:

- Rosselet et al. P.R. D15 574 (1977)
  $\simeq 3 \times 10^4$ events $a_0^0 = 0.26 \pm 0.05$
- Pislak et al. (BNL 865) P.R.L. 87 (2001)
  $\simeq 4 \times 10^5$ events $a_0^0 = 0.216 \pm 0.013_{stat} \pm 0.004_{syst} \pm 0.005_{theor}$

NA48/2 (2003) $\geq 1 \times 10^6$ events

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

$$\begin{aligned}
\mathbf{H} &= J^{\lambda}_{lep}.J^{had}_{\lambda} + c.c. \\
J^{\lambda}_{had} &= <\pi^+\pi^-|A^{\lambda} + V^{\lambda}|K^{\pm}> \\
<\pi^+\pi^-|A^{\lambda}|K^{\pm}> &= \frac{1}{m_K}(F(p_{\pi^+} + p_{\pi^-})^{\lambda} + G(p_{\pi^+} - p_{\pi^-})^{\lambda} \\
&\quad + R(m_k - p_{\pi^+} - p_{\pi^-})^{\lambda}) \\
<\pi^+\pi^-|V^{\lambda}|K^{\pm}> &= \frac{1}{m_K^2} H\epsilon^{\lambda\nu\rho}(p_{\pi^+} + p_{\pi^-})_{\nu}(p_{\pi^+} - p_{\pi^-})_{\rho}
\end{aligned} \tag{1}$$

4 complex form factors (R term suppressed by m_e)
5 kinematical variables (Cabibbo-Maksymovicz)

$$d^5\Gamma \propto \frac{(s_\pi - 4m_\pi^2)}{s_\pi}.I(s_\pi, s_e, \cos\theta_\pi, \cos\theta_e, \phi)d\Omega$$

Fermi-Watson theorem ⇒ F,G,H can be expanded in partial waves + real parameters (phases) which describe the $\pi^+\pi^-$ elastic interaction

In the Pais-Treiman approximation and assuming $\Delta I = 1/2$ rule ⇒ Rosselet et al. approach to extract a_0^0

Simulation of $K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e$

- GEANT based MC simulation of the apparatus
- the $K^{\pm}e4$ decay has been described by 3 real parameters (according to Rosselet et al.):

$$\overline{g} = g/f_s \qquad (0.86)$$

$$\overline{g}' = g'/f_s \qquad (0.87)$$

$$\overline{h} = h/f_s \qquad (-0.5)$$

  and 1 phase $\delta = \delta_0^0 - \delta_1^1$ (0.21 rad)

- The simulation has been performed with the parameter values from Rosselet et al.
- a_0^0 has been extracted using
  $2\sin 2\delta = 2(1 - \frac{4m_\pi^2}{s_\pi})^{1/2}(a_0^0 + a'(\frac{s_\pi - 4m_\pi^2}{4m_\pi^2}) + \ldots)$
- Small variations from the Rosselet et al. values don't influence significantly the result for a_0^0

$K^{\pm} \to \pi^{+}\pi^{-}e^{\pm}\nu_e$ - acceptance

$K^{\pm} \to \pi^+\pi^- e^{\pm}\nu_e$ - resolution

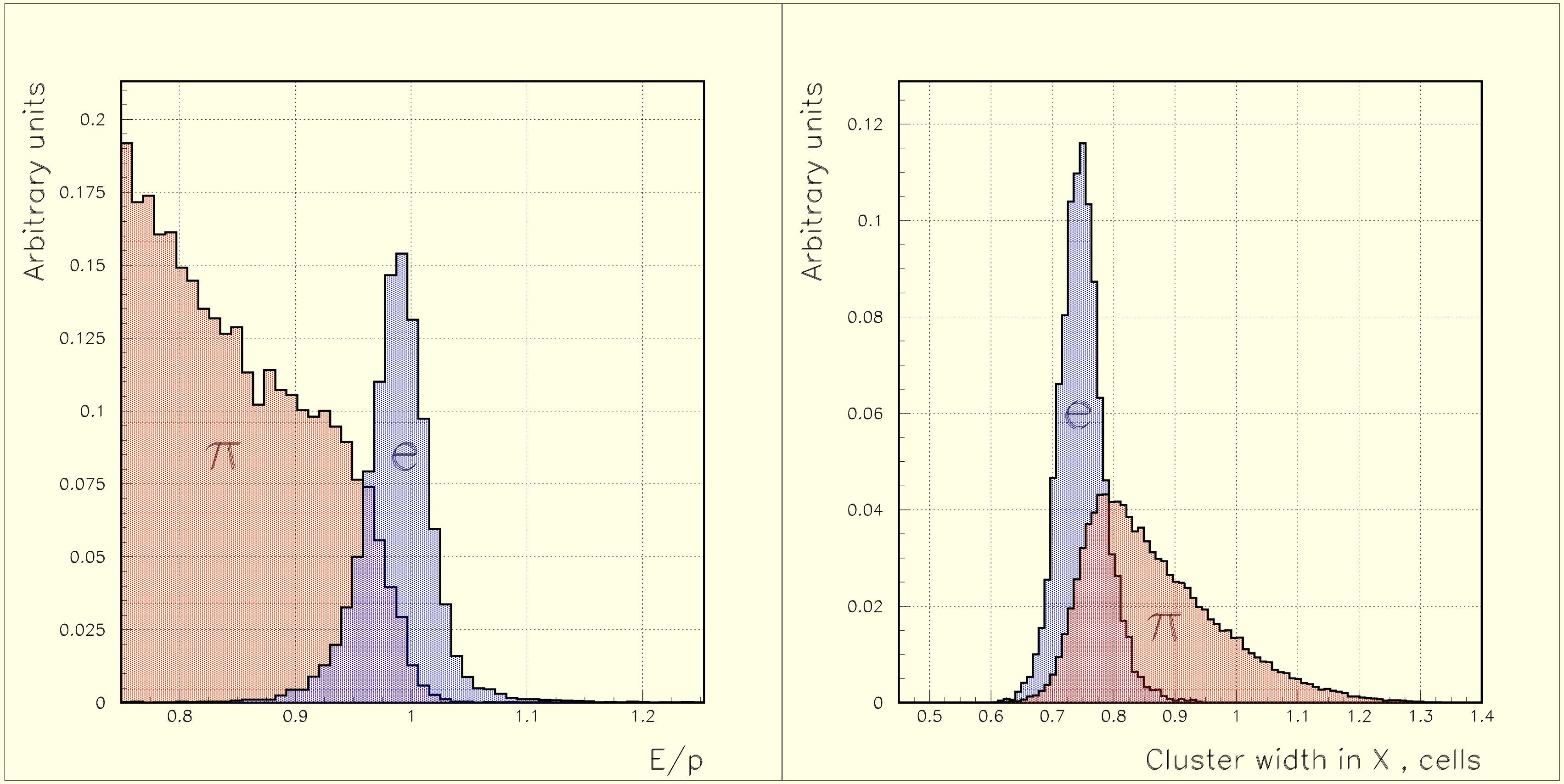
RMS	Rosselet et al.	BNL E865	NA48/2 expected
$M_{\pi\pi}$ (MeV)	2.5	16	1.6
$M_{e\nu}$ (MeV)	6.3	25	5.1
$\theta_{\pi\pi}$ (mrad)	50	63	37
$\theta_{e\nu}$ (mrad)	40	47	47
ϕ (mrad)	157	172	168

- Several times better resolution on the invariant masses (compared to E865)
- The resolution on angles is high because of the relatively high energy of the beam

e/π separation

- The separation is done using the remarkable properties of the LKr e/m calorimeter
- A *Neural Network* based approach was developed in order to exploit all available information from LKr
- The inputs to the network are:
  - E/p (Ratio of the energy of the associated cluster in Lkr to the momentum measured in the spectrometer)
  - Distance between the extrapolated from the spectrometer impact point in LKr and the cluster position (both in X and Y directions)
  - Cluster width (in X and Y)
  - Momenta measured in the spectrometer
  - The impact angles measured by the spectrometer (in X and Y)

e/π separation



Using *Neural Network* approach (on experimental data):

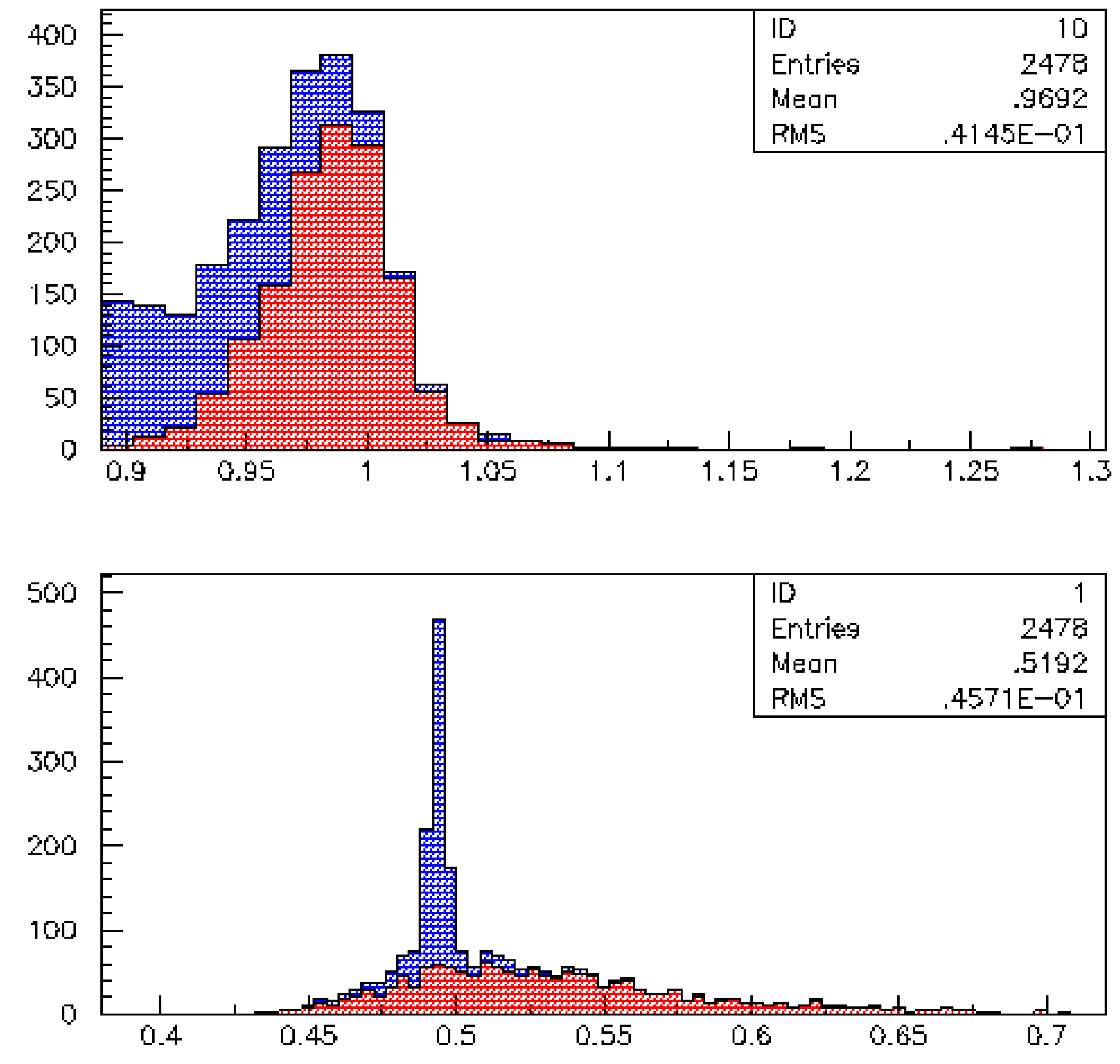
- $> 3500 : 1$ pion rejection
- $> 94\%$ electron identification efficiency

Background

Mode	Contamination in $K^\pm e4$
$K^\pm \to \pi^+\pi^-\pi^\pm$ (τ)	$\leq 1\%$ kinematic $P_t > 15$ MeV/c $E/p > 0.9$ Neural Network 1% contamination $\Rightarrow \delta a_0^0 \leq 0.01$
$K^\pm \to \pi^+\pi^-\pi^\pm \to e^\pm\nu$	$< 0.4\%$
$K^\pm \to \pi^\pm\pi^0 \to e^+e^-\gamma$	$< 0.3\%$
$K^\pm \to \pi^\pm\pi^0\pi^0 \to e^+e^-\gamma$	$< 0.1\%$
$K^\pm \to e^\pm\nu\pi^0 \to e^+e^-\gamma$	$< 0.1\%$
$K^\pm \to \mu^\pm\nu\pi^0 \to e^+e^-\gamma$	$< 0.1\%$
$K^\pm \to e^\pm\nu\pi^+\pi^- \to \mu\nu$	$< 0.2\%$

$K^{\pm} \to 3\pi$ background - test run results

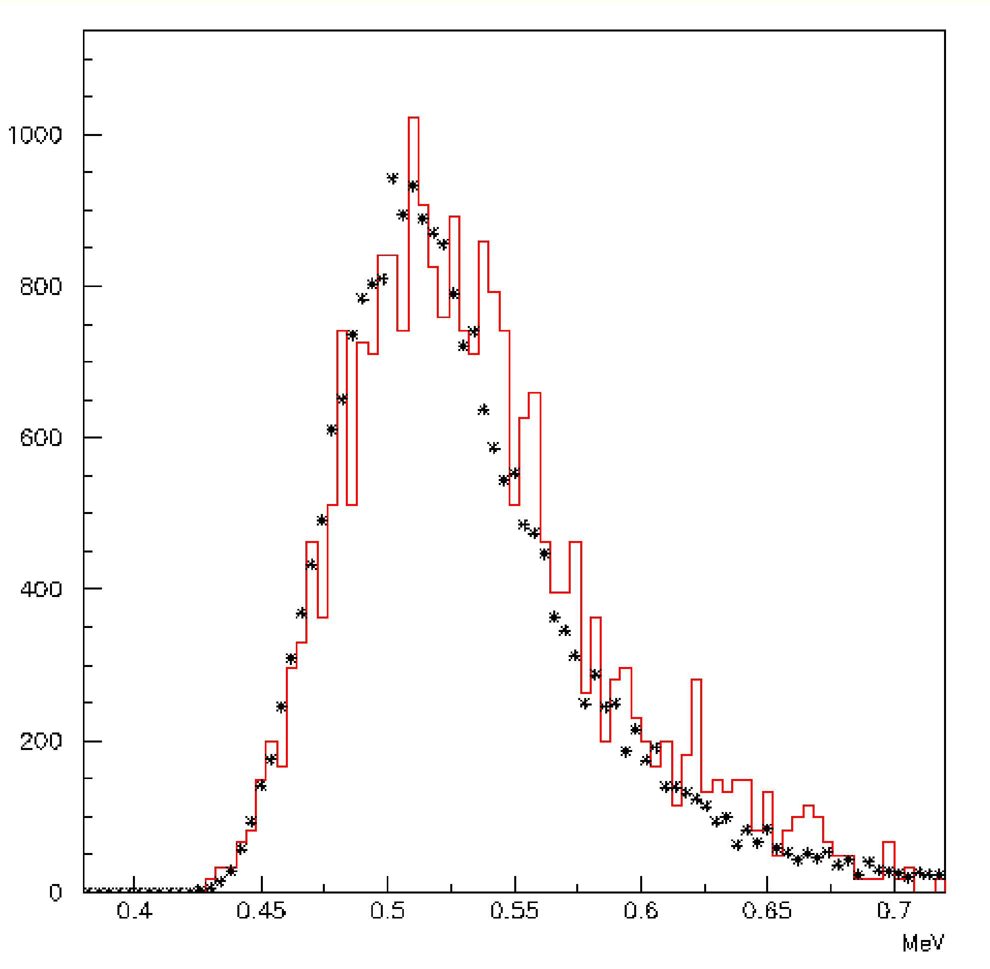
In September 2001 we performed a short NA48/2 test run.
These are the results for the $K^{\pm} \to 3\pi$ contamination in $K^{\pm}e4$:



E/p (upper) and $M_{\pi\pi}$ (lower) distributions for experimental data before (blue) and after (red) the application of Neural Network approach

Preliminary test run results

Comparison of the $M_{3\pi}$ distributions for the experimental data (solid line) and MC (*)



4 hours of data taking $\Rightarrow$

1477 selected $K^{\pm} \to \pi^{+}\pi^{-}e^{\pm}\nu$ events

Very preliminary result for the branching ratio:

$$Br = (3.75 \pm 0.25) \times 10^{-5}$$

$$PDG : Br = (4.08 \pm 0.09) \times 10^{-5}$$

Summary

- $> 1 \times 10^6\ K^\pm \to \pi^+\pi^-e^\pm\nu_e$ decays in 2003
  $\Rightarrow \delta(a_0^0)_{stat} < 0.01$
- Excellent e/π separation
  $\Rightarrow$ small background ($< 1\%\ K^\pm \to 3\pi$)
- Good resolution
  $\Rightarrow$ small binning $\Rightarrow$ control over the systematics

Excellent prospects for a precise study of the $K^\pm e4$ decay parameters!

NA48/2 is starting in June 2003 $\longrightarrow \sim$ 100 days of data taking...